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Sommaire

Introduction

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A close link between climate and agricultural production

The population of the Sahel is mainly rural and particularly concerned by climate variability as this affects food, water and financial resources and has a direct impact on public health. The economy and food security are closely dependent on rainfed farming—used on 93% of the cultivated land. The African farming sector employs 70% of total labour (FAO 2003), generates 15 to 20% of the GDP and produces 80% of the cereals consumed in sub-Saharan Africa. In addition to this dependence, rapid population growth and limited access to technological adaptations (mechanisation, fertilizers, irrigation) are factors that aggravate the socioeconomic effect of the climate (UNDP, 2004). This vulnerability to climate increased at the end of the 20th century as a result of a nearly 30% decrease in precipitation in the Sahel over a period of 40 years (Brown and Crawford, 2008) while the population doubled. The more marked famines since the 1970s necessitated international food aid and were caused partly by climatic variations (Dilley *et al.*, 2005). In this context, understanding and anticipating climate fluctuations and changes together with their consequences for farming form a major issue for socioeconomic development and food security in sub-Saharan Africa.

The expected consequences of climate change are added to these recent fluctuations. The last report of Intergovernmental Panel on Climate Change (IPCC, 2014) confirms—with increasing certitude—the global warming caused by the increase in greenhouse gases and its probable consequences for the environment and societies. In particular, it issued another warning to the international community about an increase in temperatures worldwide and a probable increase in the frequency and intensity of major meteorological events such as droughts, mentioning Africa as being one of the regions that are most vulnerable to changes in climate. Even if many uncertainties remain about the effects of global warming on the climate of Africa, such an upset will certainly have repercussions on water resources and agricultural production (CGIAR, 2009). These expected impacts form an additional constraint for a farming system that already has a precarious balance with present climatic variability, especially as regards population growth, a major challenge for agriculture. Indeed, the population of sub-Saharan Africa will double by 2050.

The need for an interdisciplinary approach

In this context of strong vulnerability to climate, it seems essential to the scientific community to describe and understand the modes of variability of the West African climate in order to improve forecasts and provide decision aid for users—whether this be to guide farming strategy or to face up to health risks that might be linked to the climate (heat waves or malaria for example). Applications and impact studies focused on water resources, agronomy and public health whose aim is to meet demand from society to devise strategies that reduce the socioeconomic impacts of variability and climate change have thus formed one of the main components of the Amma research programme (Analyse multidisciplinaire de la mousson africaine; REDELSPERGER *et al.*, 2006) that started in 2002. The programme is based on strong international coordination of different activities and includes fundamental research and programmes of observations running for several years (in particular an intensive campaign in 2006) and a true multidisciplinary effort to meet three objectives: 1) better knowledge of the African monsoon; 2) establishing links between climate variability and problems of health, water resources and food security; 3) ensuring that the results of multidisciplinary research are truly integrated in forecasting and decision. Through the multidisciplinary mobilisation generated (especially as regards common objectives in climatology, hydrology, agronomy, biology and medicine), the Amma project has been an ideal framework for setting up true dialogue between communities of scientists and users in order to respond to the priority needs of the population. It has also shown the limits of an ‘impacts’ type approach that implies a linear, one-to-one view of the climate problem and its consequences for societies. Indeed, relations between humans and their environment have complex economic, social and political configurations that must be addressed and seen together with climatic and environmental phenomena using a multidisciplinary approach. This interdisciplinary approach is crucial in problems of adaptation to environmental changes in which the response of societies is set in overall social changes.

Although these issues have a special effect in sub-Saharan Africa because of the vulnerability of the population to climate, the interdisciplinary approach to interactions between climate and societies is not peculiar to this question in Africa but corresponds to an inflection of research at the beginning of this century related to the prospect of global change and its effects. Evaluating the effects of climate fluctuations and change on the environment and society requires an interdisciplinary approach incorporating both the biophysical and human dimensions. Thus an increasing dominant role of interdisciplinarity has been observed in the past decade in the issues concerning global change of the 'Future Earth' programme of ICSU (Earth System Science Partnership of the International Council for Science) that groups major large environmental programmes (Diversitas, IGBP, IHDP, WCRP and ESSP) to create a scientific community better able to respond to the societal challenges raised by global environmental change. Another example of this trend—at the national scale in this case—is that the 2006 '*Vulnérabilité, Milieux et Climats*' programme of the ANR (*Agence nationale de la recherche*) became entitled '*Vulnérabilité, Milieux, Climats et Sociétés*' in 2008, '*Changements environnementaux planétaires et sociétaux*' in 2010 and then '*Sociétés & Changements Environnementaux*' in 2013.

The Escape Project

The interactive use of biophysical sciences (climate, hydrology, agronomy) and human sciences (demography, history, anthropology, geography) is the challenge targeted by the Escape project ('Environmental and Social Changes in Africa: Past, present and future'). From 2011 to 2015, the project assembled 8 French partners (Locean, GET, CIRAD, LPED, OMP, CNRM, LTHE, HSM) and 10 African partners (AGRHYMET, CEFORP, UCAD, LPAOSF, LASDEL, IER, DNM Mali, AfricaRice, ICRISAT), with two main objectives 1) characterisation of the past and future vulnerability of rural societies in Africa to environment and climatic changes; 2) exploration of adaptation pathways to mitigate this vulnerability. The strengths of the project lie in the extremely multidisciplinary consortium, close links between partners in the North and the South, the use of knowledge and data from existing programmes and a determination to make use of the results for societies.

While performing specific research on the recent development of the climate and forecasts and the environment and its impacts on resources the project features integration of the human dimension in the question of variability and environmental changes. This integration has been implemented by the running of case studies in Senegal, Mali, Niger and Benin. These were aimed at:

–defining the role of climatic and environmental changes in the past and present evolution of agropastoral practices and, more widely, those of rural societies;

– examining the way in which persons and groups perceive and comprehend the variability of their environment and how they integrate this by adaptation.

Unravelling this complexity of combined human and natural systems required an approach capable of responding to major issues of interdisciplinarity: 1) mastery of the basic notions of several disciplines so that multidisciplinary teams could perform joint reflection using shared concepts and questions; 2) collecting both disciplinary and integrated data at several scales in several geo-climatic regions; 3) developing analytical methods to link ceaselessly changing social and ecological factors. The Escape project has tried to meet these three objectives of interdisciplinary research.

The implementation of interdisciplinary work between natural sciences and social sciences started with discussion between disciplines and the joint elaboration of research questions. Participatory diagnostic workshops at three different locations (Bankoukou in Niger, Niakhar in Senegal and Djougou in Benin) formed the focuses for interdisciplinary exchange. The principle was the same in each case: some 15 researchers grouped in the same place for five days to draw up a rapid diagnosis of both the representations and perceptions of crop and livestock farmers with regard to climatic and environmental changes, their vulnerabilities and changes in farming systems. The workshops fostered comparison and then a preliminary synthesis (1) of the knowledge drawn from several scientific disciplines (agronomy, anthropology, climatology, demography, ecology, geography, history, etc.) and (2) between what the scientists say and farmers' knowledge and practices. On completion of the workshops, we had a more complete description of the agrarian and social system and also better identification and analysis of interactions between the social system and the natural environment. Finally, this work made it possible to achieve better interdisciplinary definition of research aims, questions and procedures while gaining better understanding of the complexity of systems in which humans and nature are paired. Two themes at the interface between several disciplines finally emerged: 1) understanding farmers' representations and perceptions of the climate by comparing them with scientific discourse and observations; 2) analysing farmers' adaptations – and capacities for adaptation – to inter-annual variation in precipitation, with descriptions of all the ecological, agronomic and social logics. Among many others, these two research themes have formed the two main areas in which the interdisciplinary work was carried out.

From a technical point of view, the work involving several disciplines was in the form—as far as this was possible—of an integrated data system developed on a collaborative basis. In contrast with strictly ecological or solely social studies that each have no knowledge of the impacts of a natural or social system on the other system, these interdisciplinary studies examine the climatic, ecological, agronomic and social dimensions of the system and their interactions. Several multidisciplinary collection methods were designed for this, with each discipline participating in the construction and interpretation of individual or hybrid indicators. Researchers in the social sciences, agronomy, climatology and soil science thus fed a shared collection tool with notions and questions specific to their disciplines. When the scale of analysis permitted, biophysical observations were paired with the statements of stakeholders. Finally, all the studies covered specific contexts over sufficiently long periods of time (more than 50 years of observations in Senegal) to shed light on the temporal dynamics and specific local features of agricultural and social patterns. The interdisciplinary research process continued with the comparison of the analysis models of each disciplinary field in order to examine threshold effects and reciprocal actions between systems. Through these studies in particular, the Escape project has made possible a visit to the complexities of the human/nature paired system that is much closer than climatic, ecological, agronomic and social investigations conducted separately. Finally, this book is aimed at identifying, analysing and interpreting all the heterogeneities of context, scale and system and all the dynamics, reciprocal effects and thresholds that bind climate, ecosystems and societies.

Description of the book

The 20 chapters written by researchers in France and Africa participating in the Escape project give a cross-referenced interdisciplinary view of past and present changes together with future scenarios of farming systems by examining how the effects of the climate interact with the other large changes in Africa (demographic changes, changes in land use, increasing urbanisation, social reconfigurations, increased poverty, etc.). As rural systems and environmental changes should be seen as adaptive and co-evolutive, the work covers the adaptation capacity of rural stakeholders (modes of access to resources, use and management of resources, capacity for adaptation to natural events) in a variety of situations in Niger, Senegal and Benin. The choice of situations is aimed at reflecting the diversity of farming systems and the variety of natural and social environments that form a constraint to this, with account taken of the social, economic and technical aspects.

Four major themes are covered.

1. Recent and future climate changes in West Africa: the obvious, the uncertain and the perceived

This theme is an examination of the climate in West Africa and addresses both the recent evolution of the climate and also the way in which the climate could change in the future because of the effect of greenhouses gases. Based on observations and modelling, it shows the considerable changes in progress with, in particular, very marked warming and an intensification of precipitations. Finally, the theme shows the way in which the population who experience this climatic variability represent and perceive the recent climate pattern.

2. Environmental changes and the impacts of the climate

As a response or not to changes in the climate, considerable changes are observed and forecast in West African environmental resources. Using historical data series from field records, satellite imagery or modelling, the theme addresses the changes in vegetation, agricultural productivity and the hydrological cycle that sometimes have tragic consequences resulting from increased flooding.

3. Societal changes of rural populations

Demographers, anthropologists, sociologists, geographers and historians address the interactions between rural societies and their environment to integrate the different time and spatial scales and observation units (farm, field, village, family or even an individual person).

This theme underlines the complexity of the relation between environmental changes and social changes that often interfere with production or consumption patterns.

4. Adaptations to farming systems, innovations

Analysis of the adaptation strategies developed by rural populations in response to the changes that they perceive. The strategies are part of a set of socioeconomic changes in which climate is one factor among others. Field surveys indicate the great reactiveness of populations; these are capable of recovering from extremely serious events such as the 1970-1980 drought and also able to profit from more favourable climatic conditions. This capacity for adaptation is guided by the memory of the populations and by a large number of socioeconomic factors that lead to varied adaptation pathways for the same measurement change in climate.

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Part I

Recent and future climate change in West Africa

Obvious features, uncertainties and perceptions

Onset of the monsoon, Boubon site, near Niamey (Niger, 2007).

Introduction

Théo VISCHEL

The last report of the Intergovernmental Panel on Climate Change (IPCC, 2014) confirms with ever-increasing certitude the global warming caused by the increased amounts of greenhouse gases (GHG) and the probable consequences for the environment and societies. In particular, it warns the international community once again of the trend towards a more extreme climate, accompanied by more frequent heat waves and extrem precipitation events. However, strong uncertainty still remains about the form of these changes in the various parts of the world. This limits scope for the reliable addressing of the question of impacts, the vulnerability and adaptation of populations and of the strategies to be set up to face them.

Study of the regional climate in West Africa thus forms part of the major international issues at the hinge point between understanding the evolution of the climate on our planet and the societal challenges for populations and decision makers in order to face up to the global changes. On the one hand, the climate in the region is governed by a monsoon system which, like the Indian and South American monsoons, plays a key role in the redistribution of water and energy in the tropics and thus contributes to global climate dynamics. On the other West African societies are well known for their vulnerability to climate variability as economic activity is based mainly on rainfed farming that is rendered fragile by management and climate risk mitigation policies that are still in their early stages and little coordinated. The major drought that hit the region at the end of the 1960s and lasted for nearly 30 years is a dramatic illustration of the impact that a substantial change in climate can have on populations. Apart from its link with global warming, that is a question that has not yet been elucidated, this major climate event indicated the need to study the climate-environment-society system as a whole.

The research conducted in the Escape project—and especially the work described in the first part—is based on an integrated approach of this kind. Here, we review the state of the climate in West Africa and its past and future evolutions in the light of climate observations and simulations, and also what is felt by the populations confronted with climatic uncertainties.

The project started with four major questions for the scientists involved, on which focuses the five chapters of this first part of the book. What mark does global warming make on the evolution of temperatures in West Africa? Since the great drought, what do we really know about the evolution of precipitations in the region and especially at the scales of impacts on hydrology and agriculture? Is it possible to use global GHG emission scenarios to plot the main lines of the evolution of the climate in the region at the horizon of the next century? Finally, how do the populations subjected to the variability of the climate perceive recent changes?

To answer these questions, researchers at the Escape project, with backgrounds in physical or human sciences, integrated the complexity and contrasts of the climate-society system in West Africa. First, because the monsoon is the result of numerous mechanisms (oceanic, atmospheric and continental) that interact at several scales of space and time. Climatology is thus marked by a strong seasonal factor and great temporal variability at the decadal, inter-annual and intra-seasonal scales and by the spatial variability from regional to local scales. Secondly, because this variability is accompanied by the sociological, economic and cultural diversity of the populations that will now live, feel and relate differently with regard to the effects of the climate and its changes.

Temperature movement since 1950 is examined in Chapter 1. This is a central variable for the study of water and energy balances, it has an impact on agricultural yields and can be a very direct threat for public health. However, temperature climatology is very little documented in West Africa. It is shown in this chapter that warming is already visible in the region but is not homogeneous. It is stronger in the Sahel than in the Sudanian and Guinean regions. The hottest periods of the year are those most affected and especially spring, when constantly rising temperatures are 2°C higher than they were 60 years ago. This amplification of the annual temperature cycle results mainly in an increase in nocturnal temperatures, with daytime temperatures remaining stable, without it being possible to explain the reasons yet.

The evolution of precipitations in the Sahel since the 1950s is reviewed in Chapter 2. In particular information is provided about the last two decades against the background of discussion of the presumed recovery of rainfall in the Sahel. In fact, analyses conducted using *in situ* rainfall data reveal regional disparities in the evolution of annual cumulated rainfall. A return of precipitation is indeed visible in the central Sahel (although this has not returned to the conditions of pre-drought years), but seems to be slow in the western Sahel where the drought continued until the end of the 2000s. Rainfall events are examined at a finer scale, showing that the recovery of rain in the central Sahel features a continued deficit in the frequency rainfall events close to that of the drought years. This is compensated by the more common occurrence of intense rainfall, with levels not seen since the 1950s. The intensification of precipitations thus better characterises the recent evolution of rainfall in the Sahel rather than a return to wet conditions.

With rising temperatures and a more intensive hydrological cycle, the Sahel has displayed for the last two decades all the signs expected of warming at a global level. To see whether this singular evolution may be the presage of change in the longer term, Chapter 3 consists of analysis for West Africa of simulations using general circulation models (GCMs) in the CMIP5 project, on which the conclusions of the 5th IPCC report (IPCC, 2014) are based. Some progresses of the GCMs made since the last similar experiment, CMIP3, are highlighted in the chapter, and in particular their capacity for finding the spatial structure of precipitation events and average temperatures. However, intra-seasonal variability is still poorly simulated by many models. In response to the increase in GHG concentration, the models all converge towards a rise in temperatures in the region over the coming century, although there is no consensus with regard to the scale of warming. Rainfall projections seem to agree on the difference in behaviour between the eastern Sahel, which should become wetter, and the western Sahel, which should become drier. However, the very strong disparity between simulations means that a reliable quantitative analysis of these trends is not possible.

Beyond the uncertainties that still remain with regard to the climate in the future, the ability of populations to perceive recent changes is very instructive for seeing how adaptation approaches can be established. This question is addressed in Chapter 4 with the evaluation in three West African countries with contrasted climates (Niger, Benin and Senegal) of how the population perceives climate changes in comparison with meteorological observations. In spite of strong local climate variability and the many factors that can interfere between the reality of measurement and cognitive experience, the surveys conducted show that perception by the population is a good reflection of recent measured climate changes. Perception is all the more accurate when changes are short and strongly marked, as is the case of the changes in the rainfall regime observed in the Sahel. Perception is less close to meteorological observations when changes—such as an increase in temperature—take place slowly or do not have an impact on the way of life of the persons concerned. It is also noted that access to meteorological information improves the ability of the population to detect changes.

Finally, it is shown in Chapter 5 that this perception of climatic and environmental changes is extraordinarily rich and varied in the populations surveyed, as are the representations that explain these changes and the many practices aimed at making a response. Beyond this diversity, the persons met at the main locations in Niger, Senegal and Benin have a very clear perception of both the changes in rainfall, temperature and winds and also of environmental changes: new features appear such as dust and certain plant species and known features disappear, such as ponds, part of the fauna and shrub and grass species.

The results described in the first part of the book are certainly of great value for the scientific community— both in the replies that they bring and the new questions raised. They show above all that the challenges raised by the complexity of regional climates, especially in West Africa, can only be revealed on the basis of long-term observation of the climate-society system. Continuing the meteorological and sociological observations is crucial for detecting changes, understanding their mechanisms, improving modelling and finally providing populations and decision makers with reliable climate information that is beneficial for their adaptation and development strategies.

Chapter 1

Climate warming observed in the Sahel since 1950

Françoise GUICHARD, Laurent KERGOAT, Frédéric HOURDIN, Crystèle LÉAUTHAUD, Jessica BARBIER, Éric MOUGIN, Birama DIARRA

Introduction

Research on climate warming has considerably grown over the past three decades or so. However, existing studies in West Africa are focused mainly on precipitation trends, with very little attention paid to the evolution of temperatures. The climate warming observed during the last 60 years is contrasted from one region to another. It is more marked in continental zones and stronger at night than during the day (IPCC, 2013). Until now, most regional studies have concentrated on climate warming in the northern and temperate zones, with much less focus on tropical and semi-arid zones. In West Africa, the very few studies addressing this question are recent and not directly based on in-situ observations but on satellite data, gridded dataset, i.e. data interpolated onto a spatial grid, and meteorological reanalyses (COLLINS, 2011; FONTAINE *et al*., 2013).

Satellite products do not give direct information about temperature evolution close to the surface, but on an entire atmospheric layer. The link between these two temperatures is far from trivial. Furthermore, satellite records only give information from 1980 onwards—a short period when set against the scales of climate fluctuations (a climatic average is typically performed for a 30-year period). Likewise, meteorological reanalyses are elaborated with physical models constrained by observations and the quality of the results is strongly dependent on the number and quality of the observations used. This is a particularly crucial issue in West Africa as data collected in recent decades are few. In addtion, there are numerous imperfections in these models, and a satisfactory simulation of temperatures close to the ground, especially at night, is difficult (SANDU *et al*., 2013). The rare comparisons of air temperature at the surface given by meteorological reanalyses also reveal large differences between one reanalysis and another, especially for the Sahel and the Sahara (ROEHRIG *et al*., 2013).

Several sets of data are used here to show how this multidecadal warming is strongly affecting West Africa and in particular how the highest temperatures, likely to have the greatest environmental impact, have changed. Here we analyse how the temperature trends are superposed on the annual cycle and also how they affect the minimum and maximum temperatures. We also include a brief description of the evolutions and trends shown by meteorological reanalyses and climate models.

Strong multidecadal warming with contrasts according to the season

Our analysis is based on data sets including local observations available at a daily time step and spatial data available at a monthly time step. The results are illustrated with data provided by local data from Hombori meteorological station in Mali (data referred to as 'SYNOP' in meteorological vocabulary) provided by the Direction nationale de la météorologie du Mali (Malian meteorological office).

These data are used in Figure 1a to show the typical trend observed month by month in the Sahel for the last 60 years (it is close to trends estimated woth the other data available for the region, as presented below). The figure indeed shows a strong increase in temperatures, but it also clearly indicates that the warming observed is not homogeneous throughout the year; it is particularly marked in spring and autumn, and higher than 1°C from March to October (in comparison with the global average warming of 0.5°C).

In Figure 1b, spatialised data from the Climate Research Unit (CRU TS3.10; MITCHELL and JONES, 2005; HARRIS *et al*., 2013) show that this warming affects the entire Sahel strip. It is weaker close to the equator and stronger in the Sahara and the western Sahel.

This trend is analysed in greater detail below, and in particular its complex annual structure that emerges from an the bimodal annual cycle of the cycle (a characteristic feature of continental tropical regions).

The Sahelian climate: temperature, humidity and monsoon rainfall

The semi-arid tropical climate of the Sahel is very hot. An example is shown in Figure 2 with data from the Agoufou automatic weather station (MOUGIN *et al*.,

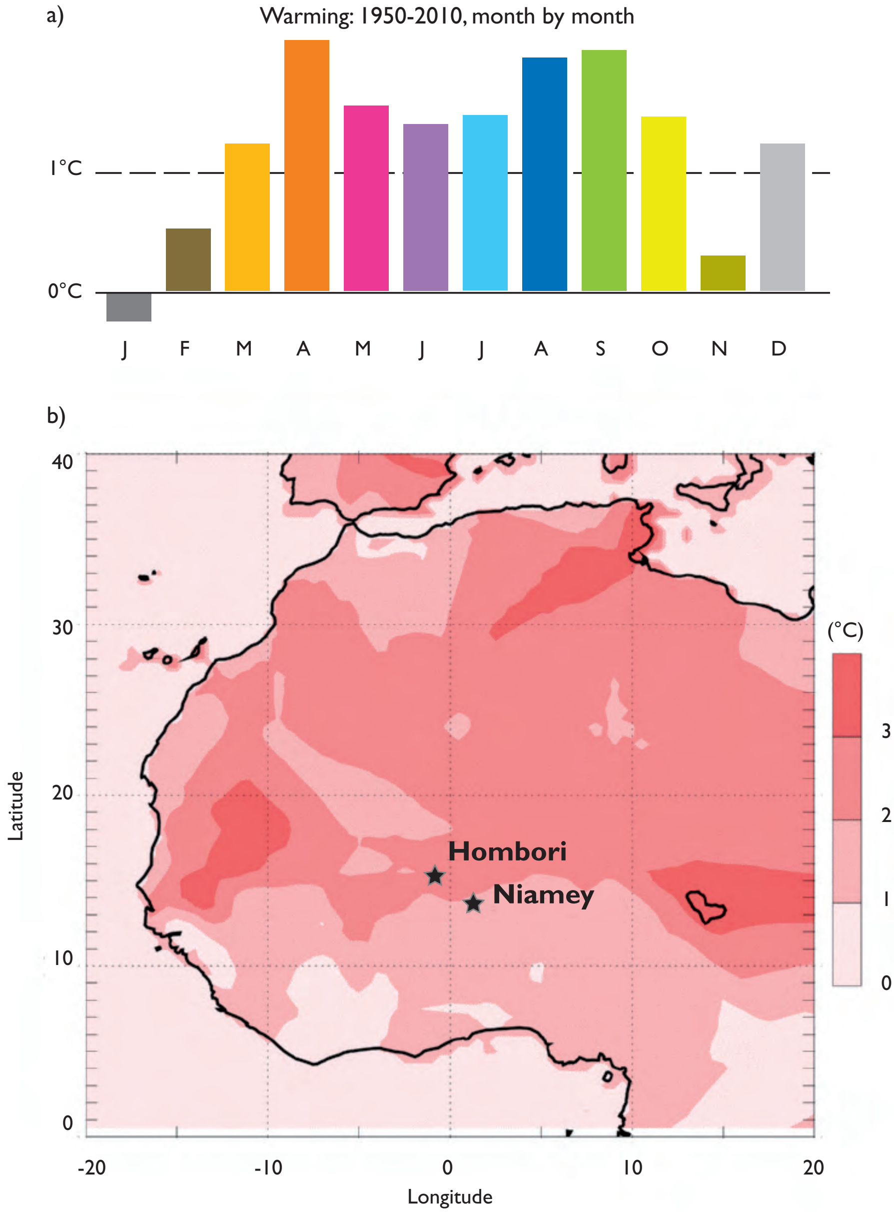

Figure 1.
Multidecadal warming in the Sahel, annual and spatial structure:
(a) increase in monthly-mean temperatures from 1950 to 2010 calculated with data from the Hombori meteorological station in the Sahel using a linear regression;
(b) maximum increase in monthly-mean temperatures from 1950 to 2010 using CRU data
(we select the month for which the trend is at its annual maximum here).

2009) in the heart of the Sahel a few tens of kilometres from the Hombori SYNOP station. Data collected over several years are overlaid and smoothed to show the annual cycle of surface air temperature, specific humidity and rainfall.

The 10-day average temperature oscillates between 20°C in winter and 35°C in spring. The hot spring period is particularly marked and long, with temperatures varying comparatively little in May. The maximum occurs shortly after a first period of peak insolation at the top of the atmosphere (Fig. 2) and coincides with the first surges of the monsoon flow, identified here by fluctuations of specific humidity that precede the first monsoon rain events by several weeks. The ground is dry and hot at this time of year. Air temperature then decreases gradually throughout the rainy season from June to August, reaching a minimum in August around the second insolation peak at the top of the atmosphere. The temperature drop observed during the monsoon is related to the strong surface cooling caused by precipitation and its evaporation. The temperature rises once again with the monsoon retreat after the last rains and reaches a less marked second annual maximum; this generally occurs in October several weeks after the second maximum of the insolation at the top of the atmosphere. Temperature does not fall until November, then in phase with the decrease in insolation.

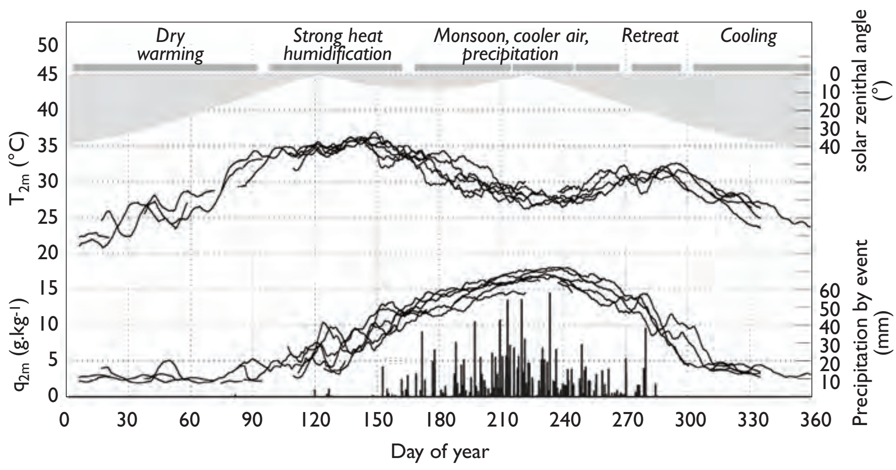

Figure 2.
The annual cycle of the temperature (upper curves) and specific humidity cycle (middle curve) 2 m above the ground surface.
The data are from the Agoufou automatic weather station (part of the AMMA-CATCH network). Observations collected over several years are overlaid and shown as 10-day sliding average series. Each of the black bars (at the bottom of the graph) indicates cumulated rainfall during a rainfall event (from 2002 to 2007). Their ensemble allows to depict the duration of the rainy season (from June to September). The succession of seasons is shown by the dark grey segments at the top of the graph; the paler areas below show the variation of the solar zenithal angle; the latter accounts for most of the fluctuations of insolation at the top of the atmosphere at this latitude (15.3° N).

This annual cycle of the Sahelian temperature is much more complex than the monomodal cycle observed at temperate latitudes. It can only be explained by considering together the geographic position of the Sahel, large-scale atmospheric circulations, notably the monsoon and Harmattan flows, and the whole series of distinct physical and biological processes that successively take place during the year. This involves precipitation, but also radiative transfer and its strong sensitivity to atmospheric humidity, the growth of vegetation, etc. Each of these phenomena in turn makes its mark on the surface energy balance—a balance that has a major direct influence on air temperature at the surface (for more details see GUICHARD *et al.*, 2009).

The annual cycle of the warming observed during the last 60-year period

The information above thus shows that climate warming is at a maximum in spring (Figs. 1 and 2), that is to say the time of year when temperatures are already very high. This feature is discussed below using Figure 3 that shows how the evolutions of temperature over the last 60 years are superimposed over the average annual cycle. Data from the Hombori SYNOP station are used here again but the conclusions are the same for other Sahelian SYNOP stations when they are sufficiently far from the Atlantic. Dakar, for example, is on the coast and the annual cycle of the temperature differs from that discussed here in that there is no spring maximum.

The time series of the monthy-mean temperatures are shown in Figure 3 for every month of the year. It appears that not only the trend but also the dispersion the series for the last 60 years vary among the different months. No distinct 60-year trends are seen during the cold dry season from November to March. In contrast short inter-annual fluctuations are dominant, especially in January and February, with monthly-mean temperatures varying by more than 5°C from one year to another. The short inter-annual fluctuations decrease in spring (April and May) and a more marked, linear climatic trend emerges (the curves overlaid on monthly series of points correspond to a quadratic adjustment). The multidecadal warming remains substantial for the four monsoon months that follow but it is weaker and less linear (the adjustment becomes concave). The 'signature' of the 1970s and 1980s droughts, which were associated with an increase in temperature, can be seen in August and September in particular. The opposite applies for the 1950s, which was the rainiest decade and the coolest during the monsoon period. There is strong correlation between precipitation and temperature during this period of the year and their multidecadal co-fluctuations explain much of the temperature variations observed in August and September during this 60-year period, a finding that is in agreement with the analysis performed at a larger scale by DOUVILLE (2006). Finally, the trend becomes more linear again with the withdrawal of the monsoon in October after the end of the rains.

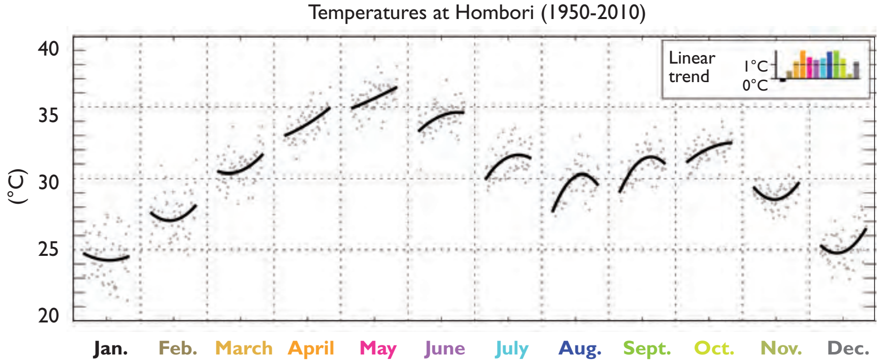

Figure 3.
Warming observed (SYNOP data) at Hombori over the last 60 years as a function of month.
For each month, the series of grey points correspond to the time series
of the monthly-mean temperature and a quadratic adjustment is overlaid (black lines).
The monthly linear trends are shown by coloured bars at the top right of the graph.

The observed warming does not alter much the cooler winter months but affects spring, summer and autumn. The increase is particularly strong in the spring but there is no apparent relation with fluctuations of precipitation as it does not rain in the Sahel at this time of the year.Thus, we observe an increase in the amplitude of the annual cycle of the temperature : the cool periods vary little while the warm periods are hotter.

The CRU Global Climate Dataset, an interpolated regularly gridded dataset commonly used for climate studies, incorporates only part of the Hombori station data used here. However, the CRU data that are the closest to the station shows similar results

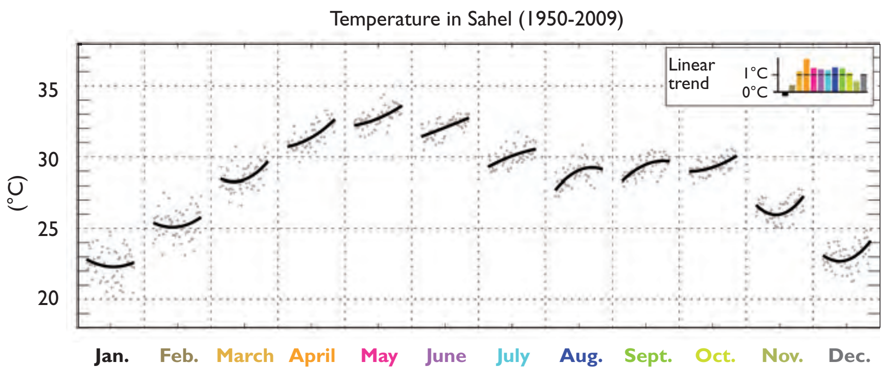

Figure 4.
Mean warming observed by month of the year with CRU data for the area
(10° W-10° E, 10° N-20° N) from 1950 to 2009
(the graphic chart is similar to that of Figure 3).

even if the trend is a little stronger by a few tenths of a degree, with warming over the 60-year period exceeding 2°C for a third of the year. More generally, the different datasets that we compared over the Sahel give similar results. The same graph drawn with CRU data for a larger Sahelian zone is shown in Figure 4. The conclusions are fairly similar again. However, the trend is now dominated by the spring warming and the second warming peak observed in the autumn is no longer seen.

The evolution of minimum and maximum daily temperatures

At larger scale, many research studies have shown that climate warming is generally greater at night than during the day (Karl *et al*., 1991, 1993; Easterling *et al*., 1997). Maximum (Tmax) and minimum (Tmin) temperatures are generally used to study the diurnal cycle, together with their difference, the Diurnal Temperature Range (DTR). The DTR is an important variable that raises numerous questions concerning the mechanisms responsible for these day/night differences. It is also important with regard to societal repercussions: in particular, excessively high minimum temperatures affect health, as the human body cannot rest and recover. They are also potentially harmful for farming as maintenance respiration increases during the hottest nights (Peng *et al*., 2004).

Using Figure 3 chart, Figure 5 shows the evolution of maximum (Tmax) and minimum (Tmin) daily temperatures and that of the DTR from 1950 to 2010. The Tmax trend is distinctly weaker than the trend of daily-mean temperature discussed above. Furthermore, the increase in Tmax mainly concerns the last months of the monsoon (August and September)—much less the spring months. An even more pronounced concave adjustment is found during the monsoon, underlining the importance of the links between temperature and rainfall during the monsoon. The trend is more linear in spring but almost half as strong. The strong warming trend in spring results mainly from the increase of the minimum temperature, Tmin, which exceeds 2°C from April to June. The Tmin trend is positive for every month of the year. It reaches its maximum in spring and is generally ‘noisier’ and less significant during the winter months. The signature of the multidecadal fluctuations of precipitation are also distinctly less marked in Tmin than in Tmax.

This different structure of the annual cycles of the diurnal and nocturnal warming leads to weakening of the DTR trend during the monsoon. However, it is still strong in both winter and spring. The multidecadal changes of the DTR are significant and several interpretations of this signature of climate warming have been proposed. Dai *et al*. (1999) analysed correlations between the DTR trend and changes in soil moisture, water vapour and clouds. It is possible that changes in soil moisture participate in the DTR trend in the Sahel. In particular, an increase in the DTR was observed in the 1970s and 1980s, the driest decade, that would be in line with a decrease in soil moisture as a result of droughts and perhaps also with the decrease in cloud cover, which would strengthen the increase in Tmax. However, the DTR trend is weakest at this time of the year, suggesting that this effect is not dominant (Fig. 5). It seems very unlikely that in spring soil moisture, unlike water vapour and

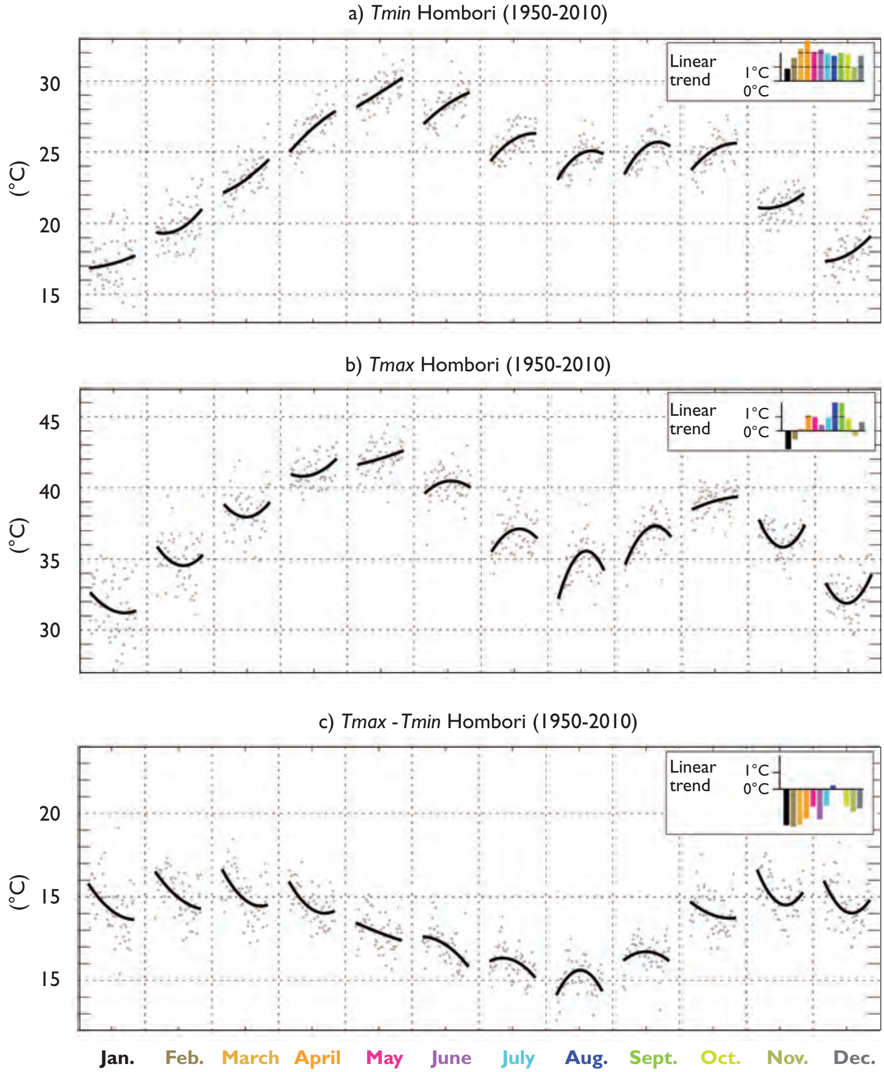

Figure 5.
Multidecadal fluctuations observed according to the month of the year with minimum daily temperature Tmin (a), maximum daily temperature Tmax (b) and Tmin-Tmax, the 'diurnal temperature range' DTR (c) at Hombori (SYNOP data). The graphic chart is similar to that of Figure 3.

clouds, plays any role, as the soil is generally dry. Finally, it is possible that in the Sahel the desert dust whose composition seems to have evolved in recent decades (PROSPERO and LAMB, 2003) contribute, like water vapour and clouds, to this trend in DTR, in particular during the dry season when the greenhouse effect of atmospheric water (in the form of water vapour and clouds) is minimal. However, the current knowledge of multidecadal changes of water vapour, clouds and aerosols in the Sahel is too partial for an accurate determination of the mechanisms that cause the observed DTR negative trend during the past 60 years.

The importance of the differences between diurnal and nocturnal temperature

Distinct annual cycles of Tmin and Tmax

As previously shown, the climatic changes in temperature take very different forms according to the season and the time of day (day/night). They are also part of a complex annual cycle whose analysis, presented below, provides a better understanding of why the signature observed in spring is so strongly marked.

The comparison of Figures 5a and 5b shows that the annual cycles of *Tmax* and *Tmin* are distinct in the Sahel. The differences between Tmin and Tmax are even more obvious in analysis of data at greater frequency in time (e.g. daily SYNOP data), as illustrated in Figure 6. In particular, the increase in Tmin from winter to spring is more marked than that of Tmax while the minimum Tmin during the monsoon is less marked than that of Tmax. Finally, the annual maximum Tmin does not coincide with that of Tmax, which is generally observed a few weeks later. Conversely, the second Tmin maximum, around the withdrawal of the monsoon in September-October, is observed earlier than that of Tmax, which occurs in October-November. Figure 5c also shows that the DTR reaches a maximum in winter and decreases during the monsoon. The top of the atmosphere receives less insolation in winter, and this tends to limit Tmax. However, in winter, the opacity of the atmosphere (which increases with the water vapour and aerosol amounts) is generally weaker as well because the air is then dry and thus more prone to low nocturnal temperatures.

Focus on the spring

The direct consequence of these differences in the annual cycles of Tmin and Tmax is that there is a time period during the spring during which Tmax begins to fall while Tmin continues to increase (Figure 6b). This period generally lasts for several weeks. The increase in minimum temperatures is usually caused by the first monsoon surges. More generally, the arrival of more humid air masses is frequently associated with a strong increase in nocturnal temperature outside of the full monsoon season (GUICHARD *et al*., 2009).

An example of these recurrent spring events is shown in Figure 7. Nocturnal temperatures (Tmin) increase sharply by 5 to 10°C and a simultaneous increase in the downwelling longwave flux is observed, consistently with the change from dry to humid air. These events are often accompanied by a decrease in daytime temperatures (Tmax) as moisture, clouds and the dust erosion accompanying them limit the solar radiation reaching the surface.

Therefore, the opposing effects of the diurnal and nocturnal trends tend to cause a considerable reduction in the effect of atmospheric circulations on the mean daily

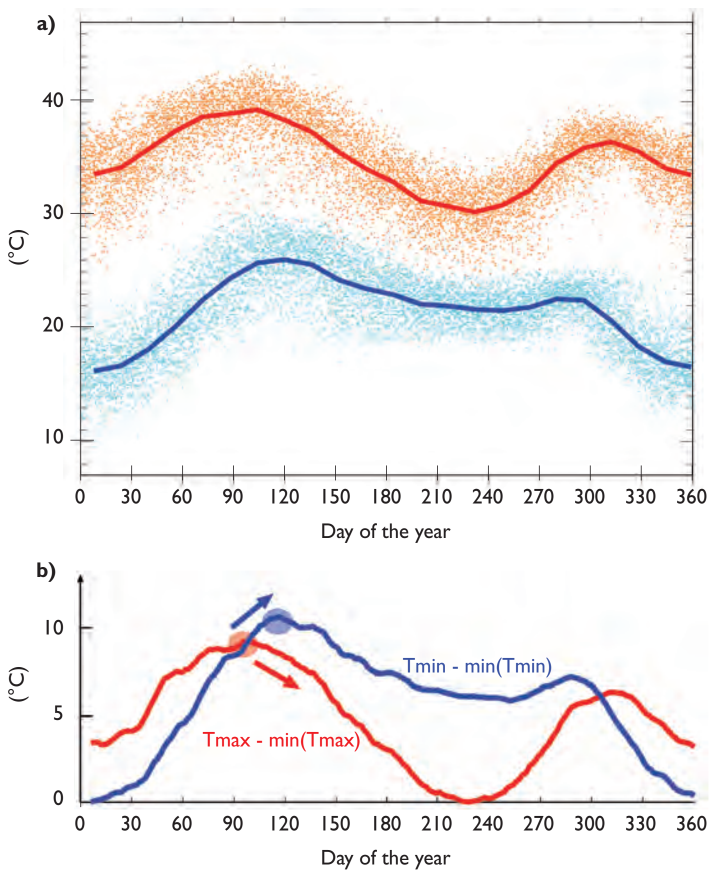

Figure 6.
Annual cycles of Tmin and Tmax : the example of Ouagadougou (use of 30 years of SYNOP data)(a) Annual Tmin (blue) and Tmax (orange) cycles. The points show daily data and the curves are 15-day sliding means, incorporating the data for the entire period. (b) As (a) except after subtraction of the annual minimum to give a more precise view of the differences in the amplitude of the annual cycles. The red circle indicates the annual maximum Tmax and the blue circle the annual maximum Tmin.

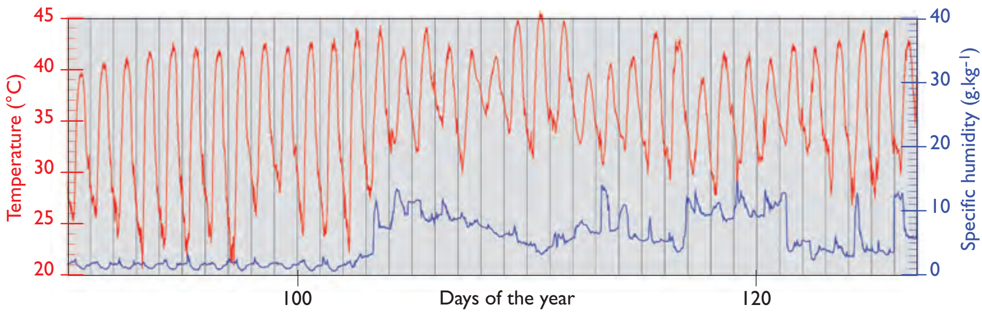

Figure 7.
A high-resolution time series (15 minutes) of temperature (red curve) and specific humidity (blue curve) of air at the surface in spring 2010. Data from the Agoufou automatic weather station.

temperature in spring, even if they are accompanied by substantial variations in diurnal and nocturnal temperatures, because they eventually tend to compensate each other. The annual maximum of temperature observed in spring is therefore fairly 'flat', with mean daily temperatures remaining high for several weeks (Figure 2).

Meridional gradient

The conclusions above are corroborated by a systematic analysis of SYNOP data from several tens of meteorological stations (Fig. 8). The annual cycle of temperatures recorded at 6 h and 12 h is shown here. The first is a good proxy of Tmin while the second is generally slightly lower than Tmax. This analysis also makes it possible to obtain information about variations of the structure of the annual cycle with latitude. The first maxima (for both Tmin and Tmax) are reached later in the year in the northern Sahel where cooling during the monsoon is less marked. In contrast, the winter cooling is more marked. These results show that analysis of an 'average Sahel' without distinction between latitudes tends to erase the extrema observed at a smaller scale.

Repercussions on the spring trends

Finally, this special balance between diurnal and nocturnal temperatures, that constrains the fluctuations of the daily mean temperature in spring, also weakens the sensitivity of temperature to atmospheric circulations at synoptic and intra-seasonal scales. It probably explains partially why short (less than 10 years) inter-annual variability is comparatively weak in spring compared with winter (Figure 2). The absence of precipitations during this period also gives a more linear signal in spring than during the monsoon because the multidecadal variability of rainfall affects the climatic evolution of temperatures during the summer. As a result, the longer-term trends are more detectable and lead in the Sahel to a particularly clear multidecadal warming signature in the spring.

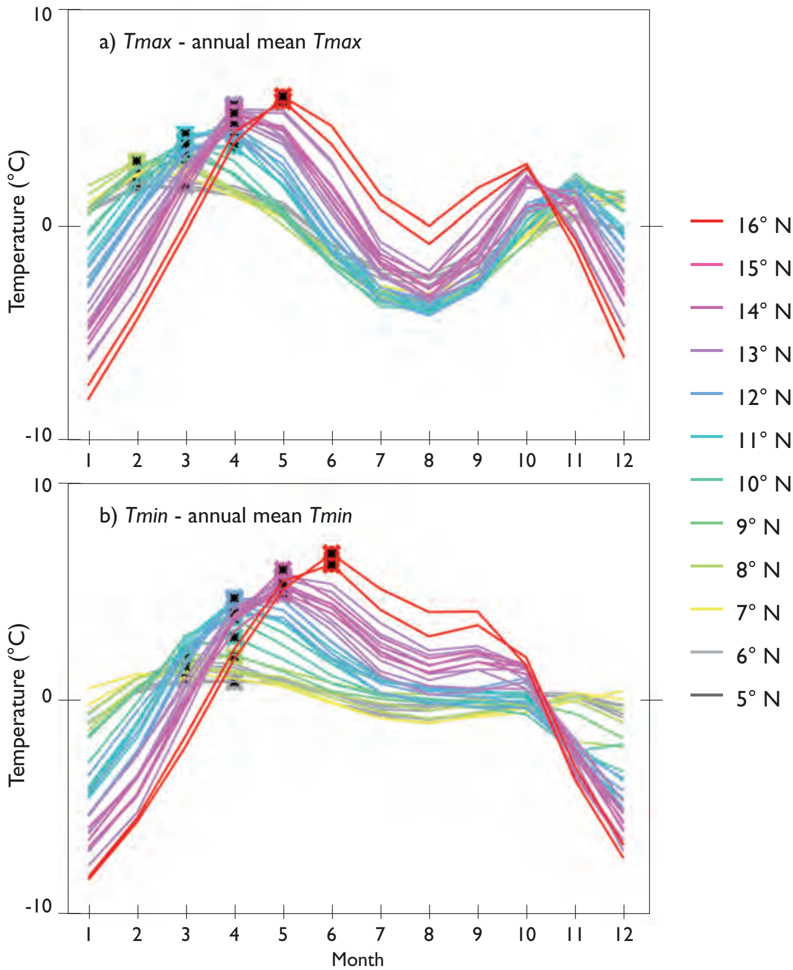

Figure 8.
Annual fluctuations of temperature according to latitude (colour code) at 12h (a) and 06 h (b).
The symbols indicate the annual maxima.
SYNOP data from around 20 stations are used here for 1980-2010.
The stations range from 5°N to 16°N and are east of 10°W
and thus exclude all the stations close to the Atlantic coast where the annual cycle is different.
The data are shown as anomalies from their annual mean values.

What can be expected from meteorological reanalyses?

These reanalyses provide data sets that are particularly useful for climate studies. However, as mentioned in the introduction, these are not observations. Indeed, comparison of the three, widely used and recent reanalyses ERA-Interim (DEE *et al.*, 2011), MERRA (Rienecker *et al.*, 2011) and NCEP-CFSR (Saha *et al.*, 2010) with the CRU data set shows considerable differences in the Sahel (Figure 9). Furthermore, the reanalyses used here only cover the last 30 years and this is short for the calculation and identification of climate trends. The comparison is nonetheless instructive.

The CRU data indicates a warming over the last 30 years on average over the whole annual cycle, but it is smaller for this period that is twice shorter. They also show a slight cooling during the last two months of the monsoon (August and September). This is probably partly linked with the transition from the 1980s, characterized by recurrent droughts, to the more recent years, which were more rainy (Figure 9, top left). A strong warming is also seen in December.

ERA-Interim generally agrees well with the CRU for both the mean annual cycle and the trends. It is slightly cooler on average (difference between the orange and red curves), but it indicates a positive, not a negative trend, during the monsoon. The combination of the ERA40 and ERA-Interim reanalyses, that makes it possible to cover a longer period, is also in good agreement with CRU data (Guichard *et al.*, 2012).

In contrast, MERRA and NCEP-CFSR diverge much more from the CRU data than ERA-Interim. They both overestimate warming in all seasons. Furthermore, the temperature fluctuations for the 30-year period provided by MERRA strongly depart from observations, with an unrealistic concave form of the quadratic adjustment from April to January (green curves). In NCEP-CFSR, the temperature evolution is dominated from March to October by an overestimation of the warming. Finally,

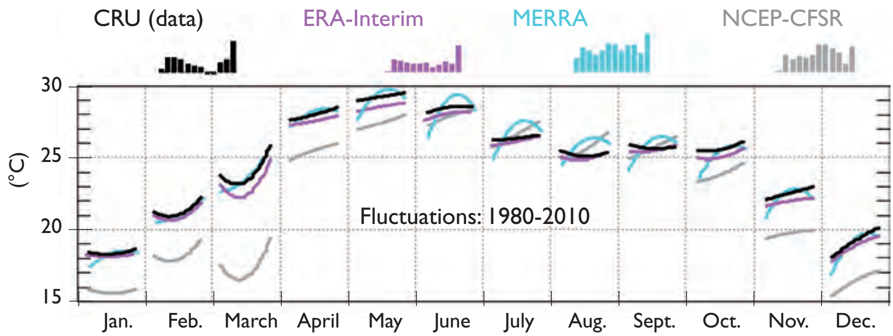

Figure 9.
Comparison of the temperature evolutions from 1980 to 2010
on average over the area (10°W-10°E, 10°N-20°N)
provided by the CRU (red) and the ERA-Interim (orange), MERRA (blue)
and NCEP-CFSR (green) reanalyses.
For clarity, only the quadratic adjustment is shown here.
For comparison purposes, the trends given by a linear adjustment
are shown at the top of the graph.
They cannot be interpreted as climate trends because the period used here is short (30 years).

this reanalysis displays a cold bias of a few degrees in most months, especially in winter. This result might seem surprising but it is nonetheless in agreement with BAO and ZHANG (2012).

In conclusion, this comparison shows that the use of meteorological reanalyses to study temperature evolutions is delicate. ERA-Interim seems to give the best chronology of the last three decades in the Sahel but it remains important to compare the information provided by this kind of product with the different data sets available in order to reach more solid conclusions.

How do climate models simulate the warming observed?

This question deserves to be asked, especially as climate models are used to formulate climate projections. As recalled in the introduction climate modelling in West Africa remains a challenge (HOURDIN *et al.*, 2010; ROEHRIG *et al.*, 2013), especially because physical processes play an important role and it is still difficult to model these with sufficient accuracy (see also Chapter 3 by Gaye *et al.*).

The results of the climate models that participated to the IPCC's CMIP5 exercise are used here and more precisely the so-called 'historical' simulations that make it possible to evaluate the models over the period 1950-2010. The simulated trends are compared with the observed trend at Hombori in Figure 10. Five of the eight models used here indicate a mean warming that is comparatively close to observations, despite differences in the overall annual structure. The DTR trends vary much more from one model to another, and this reflect large differences Tmin and Tmax trends. The comparison of other variables such as humidity also feature considerable differences between models; this suggests that the mechanisms involved in the simulated warming are not necessarily identical (for example, the daytime warming can be enhanced by a decrease in cloud cover during the day while the nocturnal warming may involve an increase in water vapour). However, it is difficult to interpret these results too literally insofar as the annual cycle of the temperature is often very approximately simulated by these models, as shown in Figure 11, on average over the area (10° W-10° E, 10° N-20° N). Most of the models effectively reproduce a bimodal annual cycle but which markedly departs from observations with differences in timing sometimes more than two months. The biases in monthly-mean temperatures reach more than 5°C in some models and those of Tmin and Tmax are generally even stronger. The interest of making a distinction between diurnal and nocturnal temperatures in the analysis of the observed temperature annual cycle and trends also indicates that it is important to correct these biases. Recent research also shows that the differences in the climate projections of climate models are linked to differences in their simulation of the mean climate (CHRISTENSEN and BOBERG, 2012).

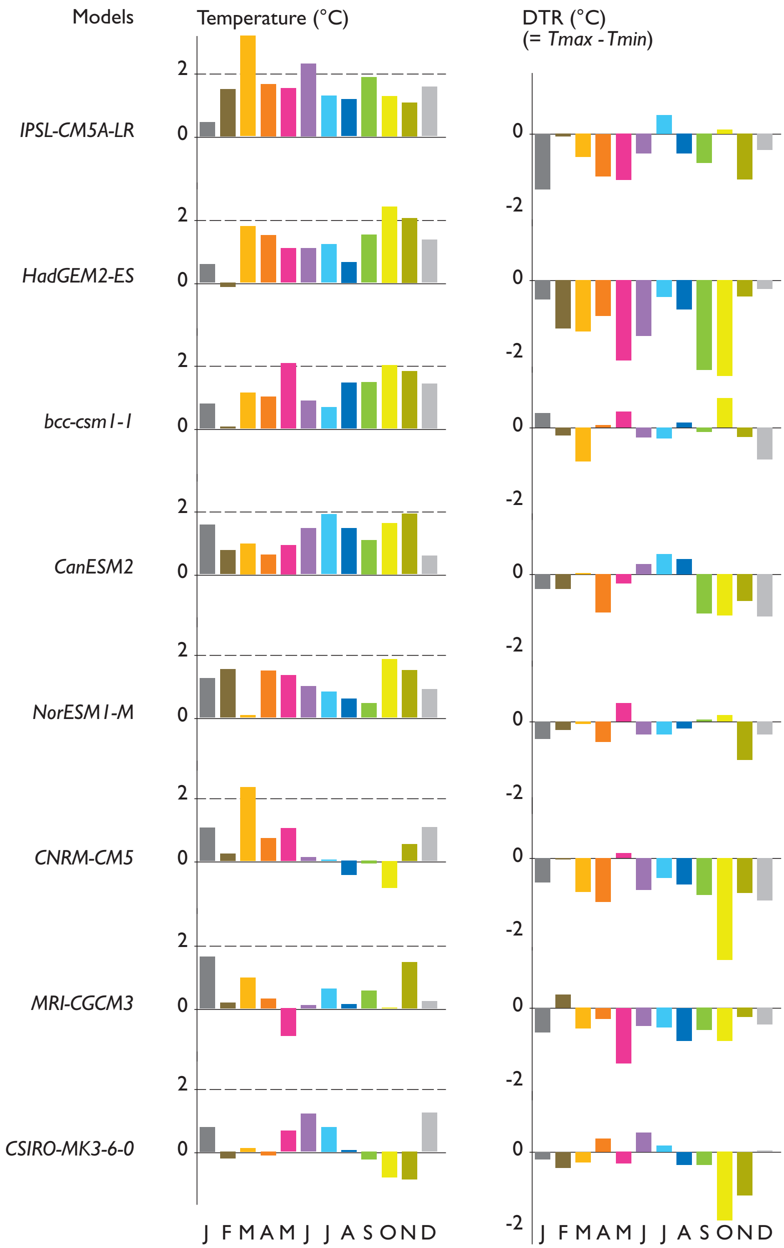

Figure 10.
Warming (left) and the DTR trend (Tmax-Tmin) (right) obtained for the period 1950 -2010 by eight climate models. The linear trends are calculated separately for each month of the year. Here we use 'historical' simulations of the IPCC's CMIP5 exercise and the point in the model closest to Hombori (1°W, 15°N). The name of each model is given in the first column on the left. The models are set in order of decreasing warming.

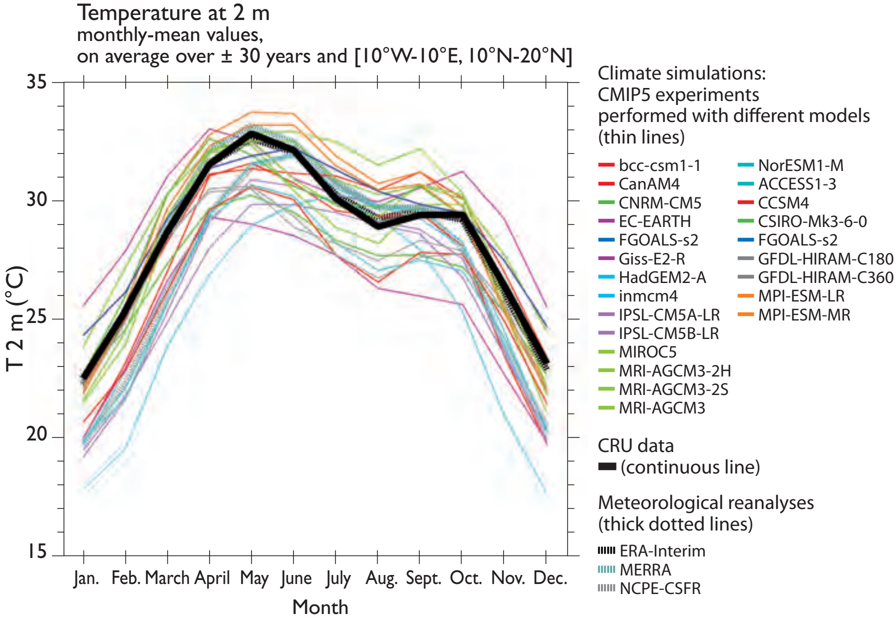

Figure 11.
The annual cycles of temperature simulated by several climate models, they were built from 30 years long time series of monthly-mean temperatures averaged over the area (10°W-10°E, 10°N-20°N). The colours identify the different models. The annual cycles of CRU, ERA-Interim, MERRA and NCEP-CFSR are also shown by thick lines (see legend).

Conclusion

The results presented here shows that the temperature has considerably increased in the Sahel since 1950. The observed warming is particularly marked and regular in spring while temperatures are already very high at this time of the year. It is also distinctly stronger at night than during the day (more than 2°C). Such a steady warming is not observed in winter as the multidecadal evolution of temperature is then dominated by strong, short inter-annual variability. It is not observed during the monsoon either, a time of year mainly affected by the strong warming observed during the droughts in the 1970s and 1980s (a warming mainly observed in diurnal temperatures). The amplitude and annual structure of the warming observed in the Sahel are also more marked than further south in the Sudanian and Guinean zones.

The annual cycle of the temperature is the result of distinct annual cycles of diurnal and nocturnal temperatures, with these being governed by different mechanisms. The multidecadal warming is also characterised by differences between diurnal and nocturnal warming. However, the mechanisms that cause this warming and its diurnal/nocturnal signature are still not clear. We expect that the mechanisms operating in spring are radically different from those operating during the monsoon, in particular because of the absence of rainfall in spring. Do they involve changes in the monsoon flow that is already present in spring, for instance via the radiative impact of water vapour, which is particularly strong at this time of year? Or because of clouds and aerosols? New research studies are essential to reply to all the questions raised. Studies considering finer time scales are also needed to determine whether the increase in monthly-mean temperatures results from evenly distributed warming or whether it is accompanied by an increase in hot days and/or nights. Recent work indicates an increase in the frequency of heatwaves in the Sahel (Fontaine *et al.*, 2013) involving large-scale circulation between the tropics and the extra-tropics. Will severe Sahelian heatwaves like the one observed in 2010 occur more frequently in a hotter climate? The impact of the rise in temperatures on agriculture also raises new questions and concerns (Sheehy *et al.*, 2005; also see Chapter 9 by Sultan *et al.*).

Existing meteorological reanalyses do not all seem capable to accurately reproduce the evolutions observed in the Sahel over the recent decades. The results provided by current climate models contain errors that make them difficult to use. However, they suggest a strong rise in temperature in the semi-arid regions of the tropics (IPCC). There are numerous potential societal repercussions of climate warming in the Sahel, especially in spring, at the end of the dry season. They may well affect health as much as agriculture, to name a few. In order to make progress on this front, it is thus important to renew our knowledge and understanding of the mechanisms that drive the observed temperatures and their fluctuations at many scales, at day and night, during heatwaves and more generally in spring, to their changes over several decades and longer periods. Observationally-based studies, process models and future developments in climate models will probably be key elements for answering the numerous questions raised by the warming observed in the Sahel since 1950.

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Chapter 2

The return of a wet period in the Sahel?

Observations and prospects

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Gérémy PANTHOU*, Guillaume* QUANTIN*,*
Aurélien ROSSI*, Maxime* MARTINET

Introduction

The question of the evolution of precipitations is of prime importance in the Sahel, a region where rainfall is at the heart of societal concerns. A deficit affects the availability of water resources and the yields of farming that is still mainly rainfed. Excess water can cause extreme hydrologic events that are harmful for populations increasingly exposed to flood risks. Precipitations are in fact the signature of the atmospheric and environmental processes that regulate the West African monsoon, which is in turn a component of the global climate system. The evolution of precipitations is thus at the hinge-point between climate variability and its impact on populations. Describing it is essential for learning about water-related risks and anticipating their future in a changing global climate.

Following the strong involvement of the international scientific community, especially at the end of the 1970s, major progress has been made in the understanding of the mechanisms of the West African monsoon, in particular thanks to an in-depth study of the rainfall regime in the Sahel. The simple description that long featured in climatological atlases of the rainy season lasting from June to September and the annual cumulated precipitation distributed along a latitudinal gradient from 200 mm in the north to 700 mm in the south (these isohyets are often put forward for the climatological delimitation of the Sahel) is now accompanied by in-depth knowledge of the long-term evolution of the rainfall regime from interannual to intraseasonal scales showing, in particular, disparities within the Sahel.

The evolution of cumulated annual rainfall figures has been studied by many scientists alerted by the drought peaks of 1972-1973 and the dramatic famines that accompanied them. The first work on the evolution of rainfall in the Sahel unsuccessfully sought signs of cyclicity in interannual variability (Bunting *et al.*, 1976). Questions were then refocused on the establishment of the drought at the end of the 1960s and then on the signs and causes of its persistence (Lamb, 1982; Hulme, 1992; Fontaine and Janicot, 1996; Nicholson, 2001; Grist and Nicholson, 2001). The updating of rainfall data to the 1990s confirmed the strong contrast between a comparatively humid period until the end of the 1960s that was followed immediately by a sudden and persistent decrease in rainfall (Le Barbé and Lebel, 1997). These studies show the regional character of drought at the scale of the Sahel, illustrated by a southward movement of the annual isohyets (decrease ranging from 20% in the south of the Sahel to 50% in the north) (Lebel *et al.* 2003). Much work has shown the statistical significance of this sharp decrease in rainfall in different regions of the Sahel (Hubert and Carbonnel, 1987; Demarée, 1990; Tarhule and Woo, 1998). Placing this evolution in perspective in a global context (Rasmusson and Arkin, 1993) now makes it possible to consider the great Sahelian drought as the most extensive and intense climate change ever measured in the world (Hulme, 2001).

At the end of the 1990s, the question of a return to more humid conditions emerged and generated controversy (Nicholson, 2013). The demonstration of overall regreening of the plant cover in the Sahel region (see Chapter 6) also seemed to support the hypothesis of a recovery of precipitation. A major obstacle for the reliable quantitative documenting of the rainfall for the last two decades is on the one hand the difficult access to post-1990 data as the national meteorological networks are degraded (Panthou *et al.*, 2012) and on the other a certain reticence of the countries in West Africa to share their data (Tarhule and Woo, 1998). Nicholson (2013) considers that this difficulty is the initial reason for the small number of studies on the evolution of rainfall in the recent period and contributes to the blank zones that still weigh on our knowledge of climatology in the Sahel.

This chapter first sets out a synthesis of recent results concerning the evolution of precipitation in the Sahel, especially over the last 20 years. We first show that signs of return of rainfall do exist but are very relative and display regional disparities. It is shown in the second part that the notion of recovery is very dependent on the scale at which it is examined, especially when mesoscale convective systems are considered as these mark the key scale of the link between climate and impact. The evolution of rainfall is addressed at the scale of hydrologic and agronomic impacts in the third part. Information is provided on the evolution of the characteristics of rainfall events, and especially the most extreme ones that were long ignored in the literature and that provide a fresh view of the direction taken by rainfall climatology in the last two decades. A balance is drawn up in the last part, providing several lines of research to be emphasised.

The return of rainfall in the Sahel: regional disparities at the annual scale

Review of recent decadal variability

Cumulated annual precipitation is the most commonly used indicator for describing the long-term evolution of rainfall. In most studies, annual rainfall anomalies are estimated by calculating a standardised precipitation index (SPI) (ALI and LEBEL, 2009). The SPI is used to distinguish between the upper and lower years of the climatological average and to use interannual and decadal variability to show the main features of the evolution of rainfall (Figure 1).

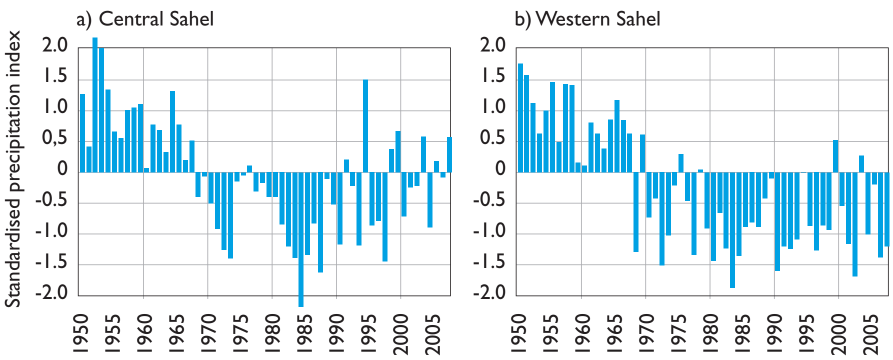

Figure 1.
Precipitation anomalies (standardised precipitation index) calculated with reference to the 1950-1989 period in the central Sahel (left) and the western Sahel (right).
After LEBEL and ALI (2009).

The question of the persistence or end of the drought was a subject for debate at the beginning of the 2000s. Analysing the SPI at the scale of annual rainfall in the Sahel until 2000, L'HOTE *et al*. (2002) held that dry conditions were still predominant at the end of the 1990s. OZER *et al*. (2003) refuted these conclusions, affirming that the drought ended in the mid-1990s. Extending the study period until 2003, DAI *et al*. (2004) and NICHOLSON (2005) did observe a tendency for rainfall to increase in the Sahel but stressed that average rainfall during the recent period was still much smaller than it had been during the 1950-1970 humid period. Using 1950-2007 information from network of rain gauges grouping a large number of national meteorological stations in the Sahel countries, ALI and LEBEL (2009) showed that the drought persisted after 1994 but there are differences in the recent evolution of rainfall in the Sahel. It can thus be seen in Figure 1a from LEBEL and ALI (2009) that although there was a decrease in rainfall deficits after 1990 in the central Sahel (defined in the window 11°N-17° N; 0°-5°E), this was marked by strong interannual variability and average rainfall remained well short of that of the 1950-1970 humid period. In contrast, in the western Sahel (defined in the window 11 N - 17°N; 15°W - 10°W) (Figure 1b), most of the years displayed a deficit whose average level was similar to that of the two preceding dry decades.

Several studies have since confirmed the evolution observed by LEBEL and ALI (2009). MAHÉ and PATUREL (2009) also propose a distinction between the evolution of rainfall between the eastern Sahel, where recovery is moderate, and the western Sahel, which has remained dry. IBRAHIM *et al*. (2012) and LODOUN *et al*. (2013) observed a gradual increase in annual rainfall in Burkina Faso from the end of the 1980s but the humid conditions of the 1950s and 1960s have not been matched. LODOUN *et al*. (2013) report very strong interannual variability, the sign of close alternation of dry and humid years that differ from the preceding periods. This feature is also observed in the Malian Gourma (FRAPPART *et al*., 2009) and more generally in the Sahelian part of the Niger River basin (TARHULE *et al*., 2014).

Variability of characteristics of the season

The decadal evolution of the seasonal precipitation cycle reveals other noteworthy differences between the central and western Sahel.

In the central Sahel, distinction is generally made between five phases in the seasonal precipitation cycle (LEBEL *et al*., 2003; SULTAN *et al*., 2003); these are traced clearly in Figure 2a for 1950-1969: (1) the establishment of the ocean phase of the monsoon causes a steady increase in rainfall from the beginning of April to the end of May; (2) rainfall stabilises in June; (3) cumulated precipitation increases rapidly at the end of June with the onset of the monsoon; (4) the continental phase of the monsoon is accompanied by a steady increase to a maximum in August after slight stabilisation in July; (5) rainfall then decreases steadily until the end of October with the withdrawal of the monsoon. In the western Sahel (Figure 2b), the seasonal signal is not marked by the onset of the monsoon and thus features three phases with the start of the monsoon followed by a steady increase in rainfall until the beginning of September and then a rapid decrease.

Analysis of the decadal evolution of the seasonal signal (Figure 2) shows that these phases are visible during all periods except for the dry years (1970-1989) in central Sahel, with (1) smoothing of the June and July peaks, thus masking the influence of the onset of the monsoon, (2) peak rainfall distinctly less than during the humid period (1950-1969) and occurring 20 days earlier. However, the decrease in rainfall in the western Sahel during the dry period is distributed much more evenly throughout the season.

It can be seen in Figure 2 that the seasonal signal for the recent period (1990-2007) is closer to that of the dry period (1970-1989) than to that of the humid period (1950-1969). In particular, the strong decrease in rainfall in the central Sahel in August and the shift in the peak season observed for 1970-1989 continued in recent years. This confirms the results reported by NICHOLSON (2005) and underlines the very relative nature of the recovery.

Three peaks can be seen—in June, July and August—in the central Sahel. These reach the level of the 1950-1969 signal but do not last as they did in the humid

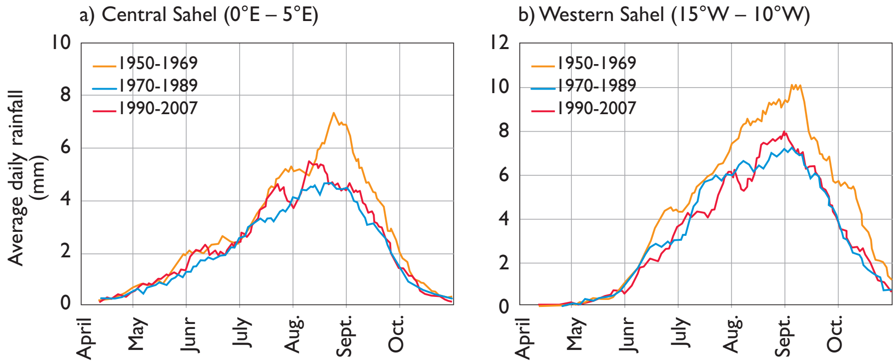

Figure 2.
Decadal evolution of the seasonal signal in central Sahel (a) and western Sahel (b).
After LEBEL et ALI *(2009).*

period. An interesting feature is the contrast in phase between the three peaks and those observed in the western Sahel during the same period; this may suggest the establishment of an east-west dipole during the continental phase of the monsoon.

Finally LEBEL and ALI (2009) note that the duration of the rainy season (defined by days with rainfall of more than 1 mm) is practically identical in all the periods. This observation is shared by IBRAHIM *et al*. (2012) in Burkina Faso and confirms the results of BALME *et al*. (2005) in Niger which show that there is no significant correlation between cumulated annual depth and the duration of the rainy season.

The recovery of rainfall in the Sahel: a question of scale

Mesoscale convective systems: a key scale in the link between climate and impact

Rainfall in the Sahel is caused by broad storm systems that spread from east to west at several tens of kilometres per hour and are referred to as mesoscale convective systems (MCSs). These account for 80% of annual rainfall, with the remaining 20% occurring during more local rainstorms (MATHON *et al*., 2002). A rainy season in the Sahel involves the passage of about 40 of these systems, making rainfall very intermittent and extremely variable in time and space. BALME *et al*. (2006 b) show that 50% of annual rainfall takes place in less than 4 hours.

The genesis and life cycle of the precipitation systems in the Sahel result from the interaction of meteorological processes across a scale continuum ranging from the synoptic to the mesoscale (REDELSPERGER *et al*., 2006). Furthermore as is seen below, the occurrence, intensity and spatial extension of MCSs modulate the internannual variability of precipitation in the long term (Le Barbé *et al.*, 2002; Lebel *et al.*, 2003; Bell and Lamb, 2006) and directly affect the distribution of surface water and in particular the partition between runoff and infiltration that controls the water cycle and the hydrological balance. The mesoscale associated with MCSs is therefore considered to be a key scale for describing hydro-climatic variability in the Sahel, at the interface between the scale of the regional features that govern the monsoon and the more local scale of hydrological or agricultural impacts (Peugeot *et al.*, 2003; Vischel and Lebel, 2007; Vischel *et al.*, 2009; Massuel *et al.*, 2011).

The impact of mesoscale rainfall on the notion of dry year and wet year

Particular effort has been made in the last 15 years to describe rainfall variability at the mesoscale. Most of the studies on the subject are based on data from the observation service AMMA-CATCH *(Analyse multidisciplinaire de la mousson africaine-Couplage de l'atmosphère tropicale et du cycle hydrologique)* (Lebel *et al.*, 2009), the only one in West Africa to provide rainfall data at infra-daily time steps and with dense distribution at three mesoscale sites (~ 10,000 km²) in Mali, Niger and Benin. The AMMA-CATCH rainfall networks have already made it possible to document the variability of distribution in terms of occurrence and intensity (Balme *et al.*, 2006 b), spatial structure (Guillot and Lebel, 1999; Ali *et al.*, 2003) and propagation (Depraetere *et al.*, 2009; Vischel *et al.*, 2011) of rainfall events associated with MCSs.

This chapter concerns a noteworthy finding concerning the contribution of MCSs to regional rainfall variability that is used fairly directly in the question of recovery and the associated spatial heterogeneity. In a recent study, Balme *et al.* (2006 a) called into question the notion of dry years and wet years by comparing annual isohyet maps plotted (1) at the regional scale using data from national pluviometric networks that are not very dense (1 or 2 rain gauges per 10,000 km²), and (2) using data from the AMMA-CATCH Niger observation network (1 to 2 rain gauges per 500 km²). It is shown in Figure 3a for 1992 that at the scale of the Sahel the spatial structure of rainfall is dominated by a latitudinal regional gradient (~ 1 mm per km). In contrast, at the scale of the observation service, local heterogeneous features are dominant in comparison with the north-south gradient as a result of several rainfall events whose positions on the ground determine the spatial distribution of rainfall, even at the annual scale. Balme *et al.* (2006 b) show that this type of very contrasted organisation is found at the observation service—whatever the year examined. The steep rainfall gradients can thus reach as much as 275 mm at gauging stations 9 km apart (in 1998) and their positions are random with regard to the network configuration and seen in both dry and wet years. The gradients can mark the spatial organisation of rainfall fields at aggregation scales of more than 10 years, as is shown in Figure 3b where, for example, a pluviometric anomaly can be seen centred on 2.2° E, 13.25° N, resulting from strong cumulation observed at the same point in 1992.

As a result, the classification as 'dry year' or 'wet year' and even 'dry period' and 'wet period' often used at the scale of the Sahel to describe the evolution of rainfall

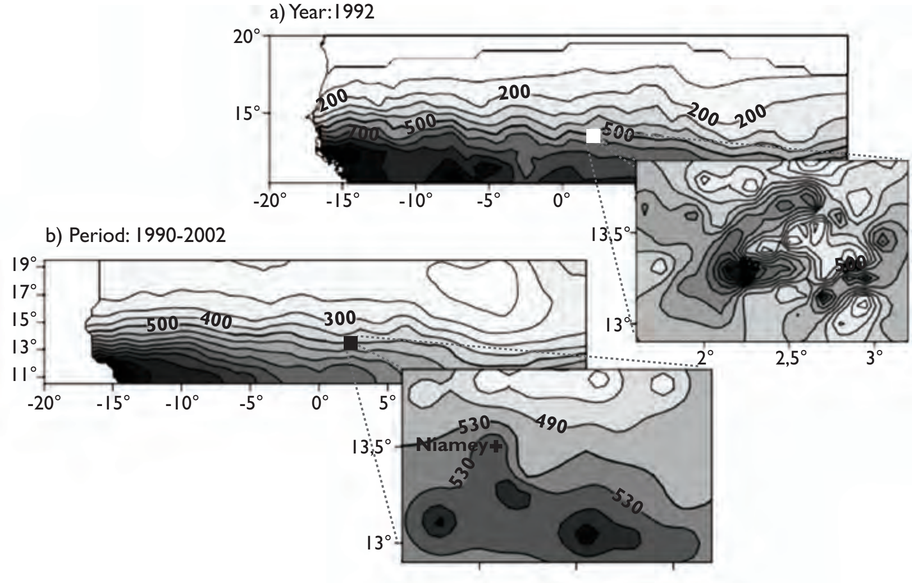

Figure 3.
Isohyets for the Sahel (isohyets at 100 mm intervals):
data from the Agrhymet centre of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) and a zoom using the dense network of the AMMA-CATCH Niger observation service.
(a) Cumulated figure for 1992 (from BALME et al.*, 2006 a).*
(b) Annual cumulated average for the period 1990-2002 (from BALME et al.*, 2006 b).*

is not very pertinent at the local rain gauge or village scale. This justifies a specific approach to the evolution of the rainfall regime at convective scales showing the questions of the impact of rainfall variability.

Rainfall evolution at the scale of hydrological and agronomic impacts

Evolution of the characteristics of mesoscale convective systems since 1950

The lack of long-term data at appropriate spatial and temporal resolutions makes it difficult to evaluate mesoscale changes over the last 60 years.

Using daily data available for Niger, LE BARBÉ and LEBEL (1997) gave a statistical breakdown on cumulated daily precipitation measured at rain gauge stations as a result of the occurrence and intensity of rainfall events. They thus show that the rainfall deficit of 1970-1990 was linked more with a decrease in the occurrence of rainfall—especially in the heart of the season—than with a change in the mean intensity of events, which remained fairly stable during the drought. These findings were generalised to cover the whole of West Africa (LE BARBÉ *et al.*, 2002) and since confirmed for Senegal (MORON *et al.*, 2006), Mali (FRAPPART *et al.*, 2009) and Burkina Faso (IBRAHIM *et al.*, 2012; LODOUN *et al.*, 2013). Although these studies provide useful documentation of the rainfall events defined at the scale of a rain gauge station, they give no indication of the possible changes in spatial morphology (size or internal organisation of intensity) of the MCSs. Defining calibrated spatial criteria in networks of daily rainfall using infrared satellite data, BELL and LAMB (2006) worked on detecting the path of MCSs on the ground, using an integrated method in 5°x 5° windows distributed through the Sahel rather than on a one-off basis. BELL and LAMB (2006) thus found that MCSs during the drought period are characterised by much smaller spatial extension and intensity than during the wet period. Although the decrease of the spatial coverage of MCSs is compatible with the local decrease (at station level) of the events shown by LE BARBÉ *et al.* (2002), their lesser intensity would appear to be in contradiction with the other studies performed on the region.

This disagreement led ROSSI *et al.* (2012) to use methodology similar to that of BELL and LAMB (2006) by updating analysis of MCS characteristics in the most recent years. ROSSI *et al.* (2012) detected ‘mesoscale rainy days’ (MRD) that, as in the work of BELL and LAMB (2006), correspond to the pattern of MCSs measured on the ground using daily rain gauges. However, in contrast with the work of BELL and LAMB (2006), the detection criteria used by ROSSI *et al.* (2012) are calibrated directly using the high resolution rainfall data of the AMMA-CATCH Niger network that provide a reliable detection reference for the MCS pattern on the ground. ROSSI *et al.* (2012) showed in particular that the relative change in the features of MRDs during the period 1990-2010 was similar to that of MCSs and hence MRDs can indeed be used to describe the long-term evolution of mesoscale rainfall.

The criteria of ROSSI *et al.* (2012) are used here to analyse the movement of MRDs over the period 1950-2010 in the central Sahel ‘window’, as defined by LEBEL and ALI (2009). The evolution of anomalies (standardised variables) of four features of MRDs is shown in Figure 4: mean occurrence, mean spatial coverage, mean intensity of positive rainfall values within the MRDs and the mean intensity of the latter (incorporating positive and null rainfall values). It is to be noted that the null rainfall values correspond to internal intermittence of the MCSs (ALI *et al.*, 2003), their frequency in rainfall systems being used to describe the spatial covers of MRDs. A synthesis of the values of the characteristics of MRDs is provided in Table 1 in the form of averages for 20-year sub-periods. Table 1 shows the well-known deficit in total annual rainfall during the 1970-1989 drought period (period P2), that is also visible in the annual cumulated MRD (forming a little more than 80% to total rainfall). The deficit results in the first order from a strong decrease in occurrence (- 19%) that started in the 1970s and became markedly accentuated at the beginning of the 1980s. The mean intensity of non-trace rainfall in the MRDs also seems to have contributed to the drought, but to a smaller degree as it fell by only 8%, in particular because of three years (1968, 1973 and 1984) with particularly marked shortfalls. Finally, as seen by Bell and Lamb (2006), a decrease in MRD spatial cover was observed (- 5%), especially during the 1980s. The major contribution of the decrease in the occurrence of MCSs during the drought is in agreement with the work of Le Barbé *et al*. (2002), especially as the decrease in occurrence combined with that of the spatial cover of MCSs automatically implies a decrease in the number of rainfall events measured at rain gauge stations. Furthermore, the decrease in MCS areas combined with a relative decrease in non-trace rainfall intensity caused an overall decrease in MCS rainfall (- 12%), but this is a secondary feature in comparison with the effects of occurrence, in contrast with what is suggested by Bell et Lamb (2006).

The comparative increase in cumulated figures (+ 13% in comparison with P2) is confirmed for the last two decades (period P3) but, as is now well documented in the literature, the level reached remained well below that of the wet period P1 (- 16%). Here, the new feature was the evolution of the characteristics of mesoscale rain systems. MRD occurrence continued to decrease after the dry period, remaining at a low level, equivalent to that of the dry period until 2000, and then decreasing further during the last decade. The intensity of non-trace rainfall returned to a stable level close to the wet period P1. Finally, a singular increase in the mean spatial extension of MRDs was observed; this reached levels that had not been observed since 1950. The increase in the intensity and size of the rain systems combined to give mean MRD rainfall nearly 14% greater than it had been during the wet period. As a result, while decadal variability in rainfall during the period 1950-1990 was modulated mainly by the occurrence of rain systems (with the decrease in the number of events accounting for more than 70% of the rainfall deficit), changes in

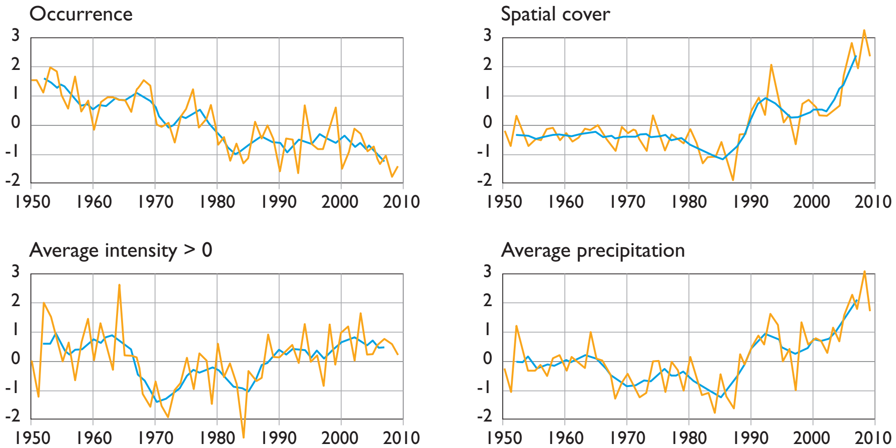

Figure 4.
Evolution of the characteristics of mesoscale convective systems using mesoscale precipitation days (MRDs) as defined by Rossi et al. *(2012).*
The blue lines represent a sliding mean for a 5-year period.

Table 1.
Mean characteristics of mesoscale rainy days (MRD).

			P1 1950-1696	P2 1970-1989	P3 1990-2009
	Tot. annual precip.	(mm)	664.2	490.0 (- *21.6%*)	553.7 (- *166%*, *<u>13%</u>*)
JPM	Annual cumulation	(mm)	537.8	404.2 (- *24.8%*)	451.2 (- *16.1%*, *<u>11.6%</u>*)
	Occurrence	(number/year)	88.7	71.95 (- *18.9%*)	60.4 (- *31.9%*, - *<u>16.0%</u>*)
	Intensity > 0	(mm)	14.8	13.6 (- *8.1%*)	15.2 (*2.7%*, *<u>11.7%</u>*)
	Intensity ≥ 0	(mm)	6.5	5.7 (- *12.3%*)	7.4 (*13.85%*, *<u>29.8%</u>*)
	Spatial coverage	(% intensity > 0)	43.2	41.2 (- *4.6%*)	48.9 (*13.2%*, *<u>18.7%</u>*)

The percentages in brackets in columns P2 and P3 represent changes in relation to Period P1 (in italics) and P2 (italics and underlined).

the intensity and spatial coverage of the system during the last two decades are dominant in the decrease of occurrence and explain the increase in cumulated annual precipitation. This behaviour appears to be a turning point in the climatology of precipitations in the Sahel and raises the question of the possible intensification of rainfall. This cannot be answered without in-depth analysis of extreme events.

Evolution of the extreme precipitation regime

Several recent studies conducted mainly at the scale of the central Sahel countries support the results described above and suggest an increase in the heaviest rainfall, based on the pattern of mean rainfall intensity, which sometimes increases in a singular manner (Lebel and Ali, 2009; Frappart *et al*., 2009; Lodoun *et al*., 2013), or on the evolution of maximum annual daily rainfall (Ibrahim *et al*., 2012). However, very few analyses have been focused specifically on the most intense rainfall in the region. The meagre documentation available on pluviometric extremes in the Sahel contrasts strongly with the number of studies on pluviometric variability related to the dry periods that affect the region (Tschakert *et al*., 2010). Until very recently, there were only two studies involving climatological analysis of extreme precipitation events in West Africa. New *et al*. (2006) analysed daily data for the period 1950-2006 from six rain gauge stations in West Africa (2 in the Gambia and 4 in Nigeria), showing significant (upward) trends in maximum annual daily rainfall at only one station. Paeth *et al*. (2010) made a detailed description of the precipitations in 2007 that caused widespread flooding in West Africa. Using TRMM satellite precipitation estimates, they considered that the 2007 events were exceptional (with a return period of several decades) in terms of cumulated precipitation for 5 to 15 days. The main reason for the small number of publications on the subject is once again linked to shortage of data and also to the methodological difficulties inherent in the study of extreme events. Indeed, extreme rainfall events are rare by definition and particularly sensitive to sampling effects, which, together with the strong interannual and decadal variability of rainfall in the Sahel make the solid detection of trends difficult.

Given these constraints, PANTHOU (2013) succeeded in assembling a set of 43 daily pluviometric series available continuously for the period 1950-2010 in a window in the central Sahel (10°N-15°N, 5°W-7°E). Statistical analysis based on the theory of extreme values provided an integrated regional view of the spatial organisation of extremes (PANTHOU *et al*., 2012) and made it possible to develop innovative methods for the robust detection of trends in series of extremes (PANTHOU *et al*., 2013). This enabled PANTHOU *et al*. (2014) to study the evolution of the extreme precipitation regime in relation to the decadal variability of cumulated annual pluviometry data. Figure 5 shows a distinct difference in the multi-decadal evolution of annual totals and daily maxima in the central Sahel since 1950. Whereas the annual totals remained markedly short in comparison with the mean for the 1950-1970 wet period, the sliding mean of annual maxima displays higher values than those of 1950-1970. The two curves are distinctly differentiated from the end of the 1990s. This confirms that an important change in the pluviometric regime occurred at the change of century, with pluviometric extremes becoming more marked.

The curves in Figure 5 were plotted using data from 43 stations, thus making a total sample of 43 annual totals and 43 annual maxima. In order to increase the size of the heavy rainfall sample, PANTHOU *et al*. (2014) used a statistical model of regional extremes to select the rainfall threshold exceeded on average *n* times per year during the period 1950-2010 at each of the 43 stations (with *n* varying from 2 to 15, corresponding to rainfall threshold figures varying with the north-south gradient). Distributions (generalised Pareto distribution - GPD) were then adjusted for each year to this bulkier sample (for $n = 10$, the annual sample is 430 figures for rainfall events of between 12 mm in the north and 32 mm in the south of the study zone).

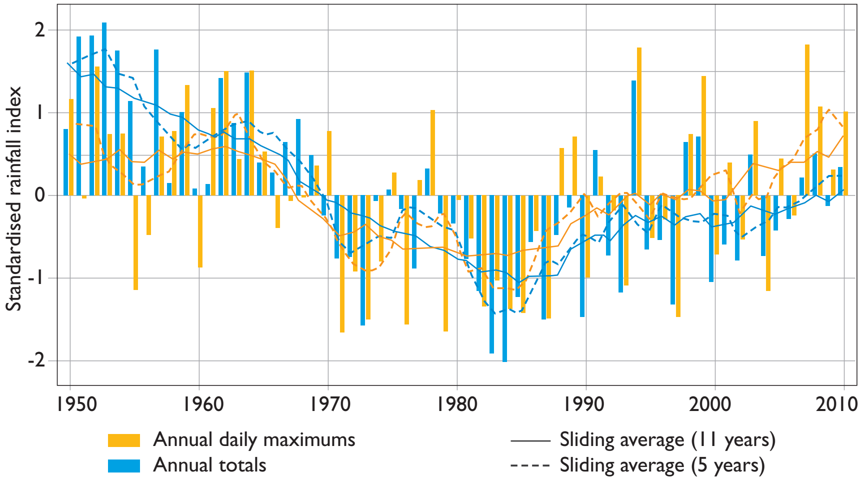

Figure 5.
Comparative evolution of annual rainfall totals and maximums in the central Sahel (window 9.5°N-15.5°N 5°W-7°E) from 1950 to 2010.
After PANTHOU et al. *(2014).*

This allows examination of the quantiles of the distributions for different values of *n*. Two major results emerge and are illustrated in Figure 6. First, the annual number of events exceeding the rainfall threshold is smaller than it was in the 1950s and 1960s except for $n = 2$ (Fig. 6a), where the level of the 1950s has been attained in recent years. However, the contribution of these rainfall events as a percentage of the annual total has increased significantly, especially when high thresholds are involved (Fig. 6b). While there has still been a deficit in the number of rainfall events, the last decade features several extreme rainfall events that were more extreme than in the past.

It is noted that for the western Sahel a recent study (Sarr *et al.*, 2013) also seems to indicate an increase in the most intense rainfall events since the 1990s. However, these results should be confirmed by a regional approach that is suited to the specific study of extreme rainfall events.

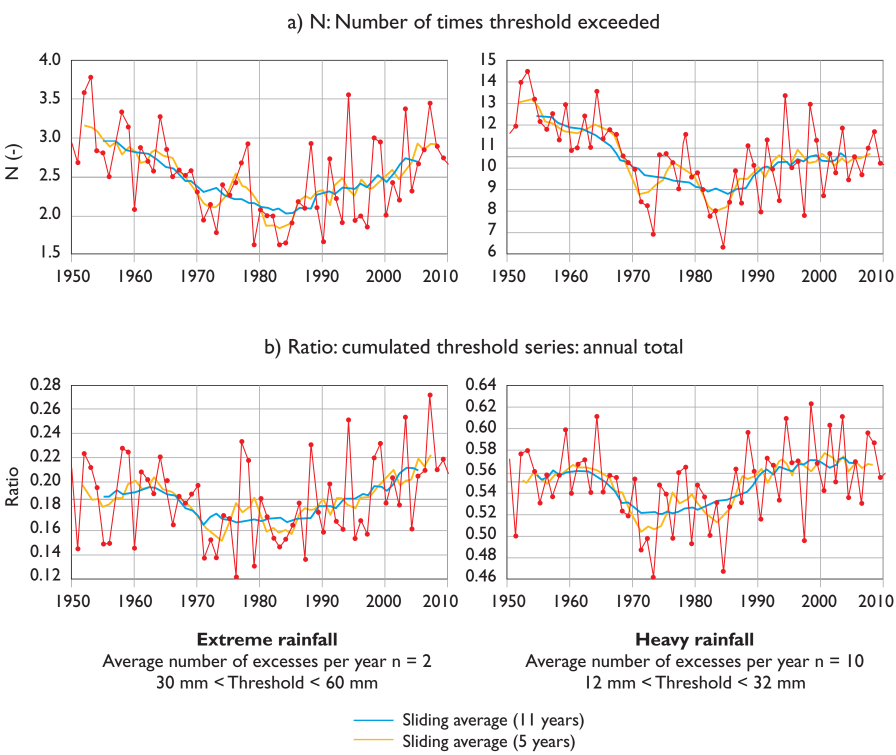

Figure 6.
(a) Evolution of the number of daily rainfall events greater than the mean n *times per year,*
(b) Evolution of cumulated rainfall exceeded on average n *times per year*
expressed as a percentage of total rainfall.
On the left, n *= 2 defines extreme precipitations*
and on the right n *= 10 defines the heaviest rainfall.*
After Panthou et al. *(2014).*

Summary, discussion and questions still unanswered

After the major drought that hit the Sahel at the end of the 1960s, rainfall recovered in the last decade of the 20th century, especially in the central part of the region but without a return to the conditions of 1950-1969, while the drought continued in the western Sahel. Beyond regional disparities, analysis of the evolution of rainfall in the Sahel is also a question of scale. When the rainfall regime is examined at the mesoscale level, the key scale for understanding the impact of pluviometric variability on the hydrological and agronomic systems in the Sahel, it is seen that the evolution of cumulated annual rainfall results from changes in the characteristics of rainfall systems that differ strongly from one decade to another.

The last 20 years of evolution of the pluviometric regime—comparatively well-documented until the 1990s—has been updated in this chapter by focus on the evolution of mesoscale characteristics and on extreme rainfall events that have been very little documented in the region. It is noted above all that the deficit in the number of days of rain has continued in the last decade but has been compensated by the more frequent occurrence of heavy rainfall linked with the most widespread rain systems. This change in the rainfall regime has had two effects: 1) a return to 'better' annual pluviometry, with the more common occurrence of heavy rain more than making up for the continued deficit in the number of days of rainfall and, 2) new modulation of the decadal pluviometric signal by the intensity of the heaviest rains.

The evolution of the regime, as shown here, leads to considering with caution the terms 'recovery' or 'a return to wet conditions' often used to qualify the rainfall of the last two decades. Although average annual rainfall is indeed greater than it has been since the 1990s, it is smaller than that of the 1950-1969 wet period. In addition, there has still been a rainfall event deficit in recent years, implying a continued risk of dry years that may potentially affect crop yields and water resources. In addition, the increase in the heaviest rainfall may cause direct damage to certain crops and infrastructure and increase risks of flooding. By combining an increase in extremes and dry periods, the Sahel displays all the signs that Giorgi *et al*. (2011) define as an 'increase in hydro-climatic intensity'. This term or that of the 'intensification of the daily rainfall regime' are therefore preferred to describe the trend taken by pluviometry in the Sahel over the past 20 years.

The results described in this chapter suggest that certain lines of research should be strengthened, including:

– analysis of the recent evolution of rainfall at intra-season scales and the mesoscale: the evolution of the rainfall regime remains at the heart of understanding changes in the climatic environment in the region. The approaches described above for characterising the evolution of the seasonal cycle and the features of rainfall events must be consolidated, first by updating the datasets for the most recent years and for the region as a whole (with strong emphasis on the western Sahel for which there is a serious shortage of information), and secondly by developing appropriate methodologies for detecting non-stationary features in rainfall series and their seasonal contrasts;

– study of the link between the evolution of rainfall and the functioning of the monsoon: the signs of the intensification of the rainfall regime are fully in line with those expected in the context of climate change; this should be accompanied by an intensification of the hydrological cycle at the global scale. Have the last two decades displayed the early signs of a more lasting change caused by global warming or do we still see the natural conditions of variability of the climate in the region? The projections drawn from climate models are still too uncertain for a clear cut answer (See Chap. 3). The reply to the question is more likely to lie in the understanding of the mechanisms (atmospheric, land surface and ocean) that have modulated the functioning of the West African monsoon and that have generated stronger hydro-climatic intensity. Much has already been published on this question (MONERIE *et al*., 2012; GIANNINI *et al*., 2013; BIASUTTI, 2013), but the work often suffers from the lack of a link with ground observations, the only objective references that enable the documentation of changes in rainfall in the Sahel;

– attribution of the increase in flood risk in the Sahel: this risk combines uncertainty and vulnerability factors. Up to now, its increase in the Sahel has been attributed mainly to (1) the growing vulnerability of populations exposed increasingly to flood risk (DI BALDASSARRE *et al*., 2010) and (2) the recent increase in hydrologic uncertainty observed in the Sahel region and resulting directly from the increase in runoff coefficients caused by changes in the state of ground surfaces (DESCROIX *et al*., 2009). These two points cannot be contested and have obviously contributed to the increase in the flood risk in the region. However, the intensification of the rainfall regime may also have played a role (see chapter 7). It would thus be important to be able to quantify the share of each of the three factors in the increase in the flood risk.

However that may be, finding answers to the major scientific and societal questions raised in the Sahel today requires access to the long-term meteorological data for the region. The contribution of national meteorological services must be strengthened for this by a clear, constructive policy of collaboration set in the ongoing international data sharing procedure in order to achieve better surveillance of the global climate change that is a threat to the world. To complement data from national networks, initiatives for denser observations in the region must also be supported on a long-term basis. The AMMA-CATCH observation service forms part of such an approach. It provides the scientific community with sets of data consisting of high-resolution documentation of the hydrological cycle, forming an excellent base for analysis of hydro-climatic variability. It operates as a laboratory for the development of key methodology for better understanding of the major environmental changes affecting West Africa.

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Chapter 3

Climate projections in West Africa : the obvious and the uncertain

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Introduction

A serious drought hit West Africa in the 1970s (NICHOLSON, 1980; HELD *et al*., 2005) whose consequences for agriculture—the main activity of the people in the region—made a serious contribution to late development. Rainfall in the Sahel seems to have recovered since the 2000s, although it is not possible to say whether the trend will last during the coming decades (PAETH and HENSE, 2004). This period also coincided with warming that probably resulted from the increase in greenhouse gases (GHG), thus making knowledge of the evolution of rainfall a crucial subject. Indeed, decades of drought punctuated by famines, displacements of populations and economic collapse were replaced by or compounded with heatwaves, flooding in many cases, new outbreaks of certain vector diseases with strong impacts on the health of populations.

In addition, as part of the ongoing climate change, the rainfall regime in West Africa is among those with the greatest uncertainty. This is shown simply by examining the results of the CNRM and the IPSL that were part of IPCC's CMIP3 (Climate Model Intercomparison Project 3) and that give contrasting precipitation projections for West Africa towards the end of the 21st century (JOUSSAUME *et al*., 2007). This is corroborated by all the models participating in the CMIP3 (whose results form the basis of the IPCC 4th report AR4); half of these indicate an increase in precipitations in the Sahel and the other half give the opposite scenario (CHRISTENSEN *et al*., 2007). Likewise, COOK and VIZY (2006) have shown that only a small number of the general circulation models (GCMs) used for the 4th IPCC report were capable of providing a satisfactory representation of the main characteristics of the West African Monsoon

(WAM): precipitation structure, meridian atmospheric circulation, the main inter-annual variability modes, etc. The 4th IPCC report thus concluded in 2007 that coupled climate models were not yet capable of simulating the climate in West Africa with precision (RANDAL *et al*., 2007). However, regional and global atmospheric models forced with the temperatures observed at the surface of the sea (SST) in projects such as AMMA-MIP (African Monsoon Multidisciplinary Analyses—Model Intercomparison Project; HOURDIN *et al*., 2010), WAMME (West African Monsoon Modeling and Evaluation; XUE *et al*., 2010) and CORDEX-Africa (Coordinated Regional Climate Downscaling Experiment; JONES *et al*., 2011, NIKULIN *et al*., 2012) gave better results for the WAM although there is still considerable bias in precipitation and meridian circulation. This is the challenge that CMIP5 aimed at taking up and whose work forms the basis of the 5th IPCC report, AR5. Thus some 20 modelling groups from about 10 countries within the framework of CMIP5 conducted a series of coordinated, standardised experiments (TAYLOR *et al*., 2012) and several questions raised still remain. Are there still Sahel rainfall projection divergences between the models? Do the GCMs reproduce the return of rainfall in recent years? What capacity do GCMs have for reproducing the main features of the WAM? What are the climate projections for West Africa in the years to come, over the next century? What evidence and uncertainties are observed in climate projections for West Africa?

These questions are addressed here using the philosophy of the major lines of the Escape project, that is to say by performing a diagnosis of what happened in the past, what is happening today and what will happen in the light of the possible consequences of climate variability and change for resources and vulnerable economic sectors. The aim is thus to be able to provide the most accurate and objective information for the political authorities and the population to enable them to implement mitigation strategies in the face of a late rainy season, extreme climatic events (heatwaves, floods, etc.) and adaptation strategies for populations and economies in the face of climate change.

We first describe the data used for the evaluation of the CMIP5 models available for the study. The second part includes analysis of the capacity of CMIP5 models to reproduce certain key features of the WAM. The third part is a discussion of climate projections (via rainfall and temperature data) for West Africa in the coming decades and especially those for the end of the 21st century. The obvious features and uncertainties of these projections are covered in the fourth section, with the chapter being completed by conclusions and prospects.

Data and methods

Numerical simulations, re-analysis data and observations are used to reply to the three questions of the introduction. In study of the climate and its variability, it is essential to possess long time series with few missing figures for the zone studied; the re-analyses and satellite observations used in this work have these advantages.

CMIP5 simulations

Use was made of available simulations from a dozen models that participated in CMIP5. The climate change scenarios (RCP2.6, RCP4.5 and RCP8.5) were compared with simulations of the past climate (referred to as 'historical') to study the response of the West African climate to increased atmospheric CO_2. Simulations with prescribed SSTs, called AMIP simulations, were also analysed to assess the state of the art of the representation of the WAM in the GCMs. The simulations used are available at http:/cmip-pcmdi.llnl.gov/cmip5/index.html.

Reanalysis and observations

CMIP5 climate simulations were compared with several datasets consisting of reanalysis and observations: (1) the first set consists of NCEP/NCAR rainfall and temperature (KALNAY *et al*., 1996) at a resolution of approximately 280 km. This dataset drawn from the reanalysis of all the observation data available (from meteorological stations, weather buoys, radiosondes, aerial observations, etc.) using a high-performance integration system covers the period 1957-1996; (2) the second dataset is drawn from ERA-Interim reanalysis (SIMMONS *et al*., 2008) by the European Centre for Medium-Range Weather Forecasts. The data are constructed using a method similar to those of NCEP/NCAR and cover the period 1958-1997 at a resolution of some 160 km; (3) the third validation dataset is version 2 of GPCP (Global Precipitation Climatology Project) precipitation (HUFFMAN *et al*., 2001). GPCP precipitation was obtained by combining ground rain gauge data and indirect satellite observations. The data used are for the period 1997-2006 with resolution of 100 km for daily data and 280 km for monthly data; (4) CMAP (CPC Merged Analysis of Precipitation) precipitation figures (XIE and ARKIN, 1997) form the last dataset for the validation of CMIP5 models and were also obtained by combining rain gauge and satellite observations; (5) CRUTS2.1 (Climatic Research Unit TimeSeries) data (MITCHELL and JONES, 2005), based on observations from more than 4,000 meteorological stations, cover the period 1901 to 2012; (6) TRMM rainfall data (HUFFMAN *et al*., 2007) were the sixth dataset used to validate the CMIP5 simulations.

The representation of several features of the WAM in the CMIP5 models

The key features of the WAM for which the models have clear weaknesses are examined here. This is to allow better assessment of the robustness of their projections—discussed in subsequent chapters.

The seasonal cycle of the WAM

The seasonal cycle of the monsoon is the most important feature for local populations whose main activity is rainfed farming. It displays alternation between a dry season and a rainy season during which the Sahel receives most of its precipitation. Rainfall structure in the rainy season is set around the Intertropical Convergence Zone (ITCZ), with three regional maximums: one centred in the western part of the continent towards 8° N in the Fouta Djalon uplands, a second towards 10° E near Mount Cameroon and a third near the Ethiopian high plateaux towards 40° E (not shown in the figures). The two maximums are fairly well reproduced by the ERA-Interim, CMAP and GPCP observations and their mean (Fig. 1a). GPCP gives comparatively lower values while the ERA-Interim maximums are generally greater than those of CMAP. The Russian model INMC4 stands out by its too marked under-estimation of the maximums of Fouta Djalon (Fig. 1b) while the models ACCESS1-0, ACCESS1-3, CMCC-CM, FGOALS-g2, IPSL-CM5A-LR and IPSL-CM5A-MR find a maximum in the west rather than over the sea. However, the two last French models (IPSL-CM5A-LR/MR) clearly show the maximum at Mount Cameroon. The Japanese model MIROC5 exaggerates the westward spatial extent, showing a zone running from 20°W to 10°E. But the models BCC-CSM1-1, BNU-ESM (although they underestimate the maximum at Mount Cameroon), CNRM-CM5, CSIRO-Mk3-6.0 and IPSL-CM5B-LR give a fairly accurate picture of the maximums at Fouta Djalon and Mount Cameroon. Finally, in spite of the dispersion in JAS (July – August – September) precipitation climatology, the ensemble mean of the 13 models is a fairly good representation of the maximums in West Africa and on Mount Cameroon.

Figure 2 shows the surface temperature climatology of the JAS season for 1989-2002, observations (2a) and CMIP5 models (2b). CRU observation data show the temperature gradient in West Africa, with low temperatures in the southern part (to approximately 13°N) and high temperatures in the north, marked by a maximum in Algerian Sahara between 25° and 28°N. NCEP and Era-Interim reanalyses give a fairly clear picture of the high temperature zone: the first model gives a lower, more extensive maximum than that of CRU, while the second gives a high maximum with greater spatial coverage. Half of the CMIP5 models give too strong an underestimation of the maximum temperature in the Sahara (ACCES1-3, INMCM4, IPSL-CM5A-LR, IPSL-CM5B-LR) or place it further south at the frontier between Mauritania and Senegal (ACCESS1-0, ACCESS1-3, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR). A second group of models (BCC-CSM1-1, BNU-ESM, CMCC-CM, FGOALS-g2) gives a fairly good picture of this maximum, but more in the north of Mauritania and Mali. Finally, only two models (CSIRO-Mk3-6.0 and MIROC5) show the Sahara maximum well, with figures comparable to those of CRU, but overestimate the maximum in the east towards 20° E (between Niger and Chad), while the CNRM-CM5 model underestimates it but positions it well. As for precipitation, it is noted that the mean of all the CMIP5 models gives a fairly good picture of maximum temperatures in the Sahara and further east in the continent towards 20° E, but with slightly lower values.

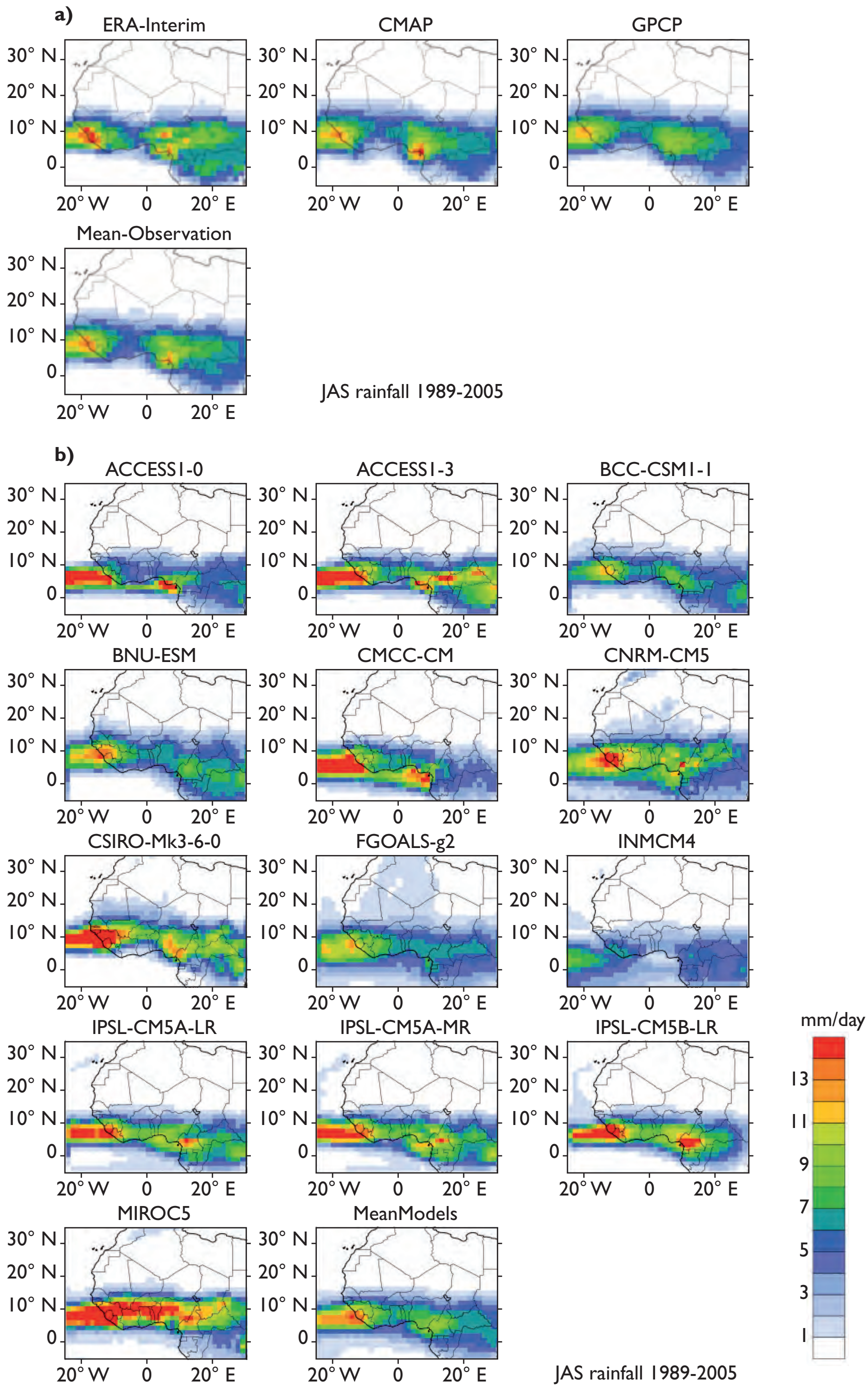

Figure 1.
1989-2005 precipitation climatology for the JAS (July – August – September) rainy season: comparison of observations (a) and of CMIP5 models (b).

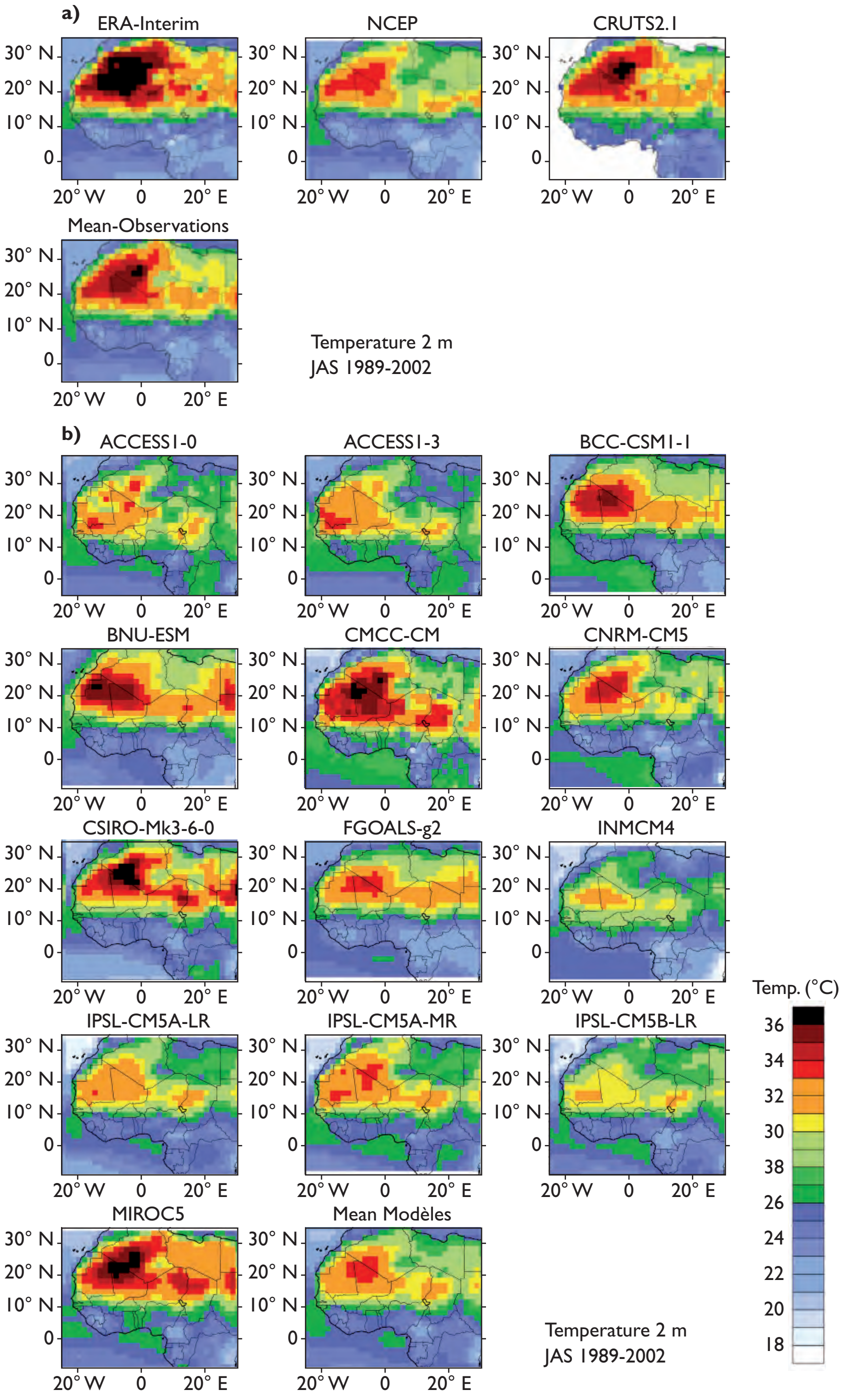

Figure 2.
1989-2002 temperature climatology for JAS (July – August – September) rainy season: comparison of observations (a) and of CMIP5 models (b).

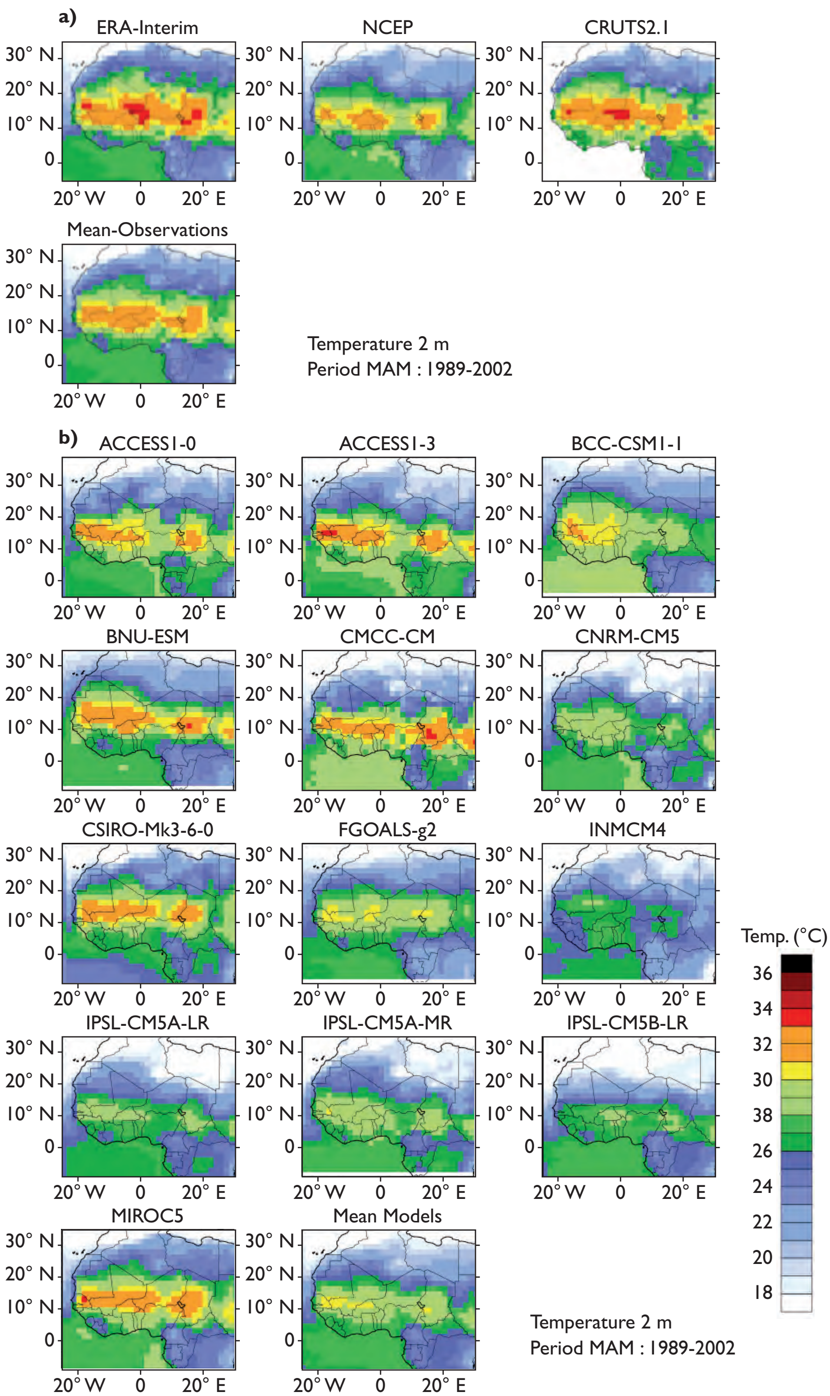

Figure 3.
1989-2002 temperature climatology for the MAM (March-April-May) dry season: comparison of observations (a) and CMIP5 models (b).

We studied the behaviour of the models during the dry season from the angle of the questions raised by the ACASIS project (*Alerte aux canicules au Sahel et à leurs impacts sur la santé*, Alert on Sahelian heatwaves and their impact on health), which has just started. Surface temperature climatology in MAM (March-April-May) is shown in Figure 3 for 1989-2002, with comparison of observations (3a) and the CMIP5 models (3b). Observations show overall that the high temperatures are found in the Sahel during the dry season, with three maximums: one towards the west (along the frontier between Senegal and Mali), a second around Niamey in the centre of the Sahel and a third towards 20°E in Chad. There is practically complete agreement between CRU and ERA-Interim while NCEP does find the position of these maximums but with much smaller values. Some CMIP5 models underestimate these maximum temperatures too markedly (IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR) or do not show them at all (INMCM4). A second group of models (BCC-CSM1-1, CNRM-CM5, FGOALS-g2) gives a somewhat poor representation of the structure of temperature climatology in MAM, with the maximum in the west found in the right position but missing that of the centre of the Sahel (BCC-CSM1-M1, FGOALS-g2) or underestimating temperature maximums (CNRM-CM5). A third group of models (ACCESS1-0, ACCESS1-3, BNU-ESM, CMCC-CM, CSIRO-Mk3-6.0, MIROC5) shows the three MAM temperature maximums fairly well even though some are underestimated.

Onset of the monsoon

We have described the importance of the seasonal cycle of WAM for the local populations. In fact the seasonal cycle of the WAM that is accompanied by the northward shift of the ITCZ does not take place steadily but in the form of a rapid movement lasting about 10 days that is referred to as the 'onset of the monsoon' (Sultan and Janicot, 2000, 2003; Le Barbé *et al.*, 2002). This feature is very important for the population of the Sahel as it signals the start of 'useful' rain for farmers (Ati *et al.*, 2002). However, Cook and Vizy (2006) showed that for the 4th IPCC report a third of the models did not provide good simulation of the WAM and in particular did not shift the ITCZ to the continent during the northern summer. Other authors (Hourdin *et al.*, 2010, Roehrig *et al.*, 2013) showed that in an AMIP mode (in which the SSTs are forced by observations), the models give better simulation of the shift of the ITCZ to the continent.

This is why the seasonal pattern of precipitation averaged for 10°W-10°E is shown in Figure 4 for CMIP5 models in an AMIP experiment and compared with GPCP and TRMM observations. The three phases of the WAM are shown clearly by the GPCP data. In the first phase, peak precipitations remain centred south of 5°N until the end of May and precipitation then decreases before increasing strongly near and north of 10°N, indicating the beginning of the rainy season in the Sahel (second phase) and reaches a peak in August. In the third phase—from August to October—GPCP shows a southward return of maximum precipitation, corresponding to the second rainy season in the Guinea region. The CMIP5 models examined show almost the same results as those of Cook and Vizy (2006): more than half do not

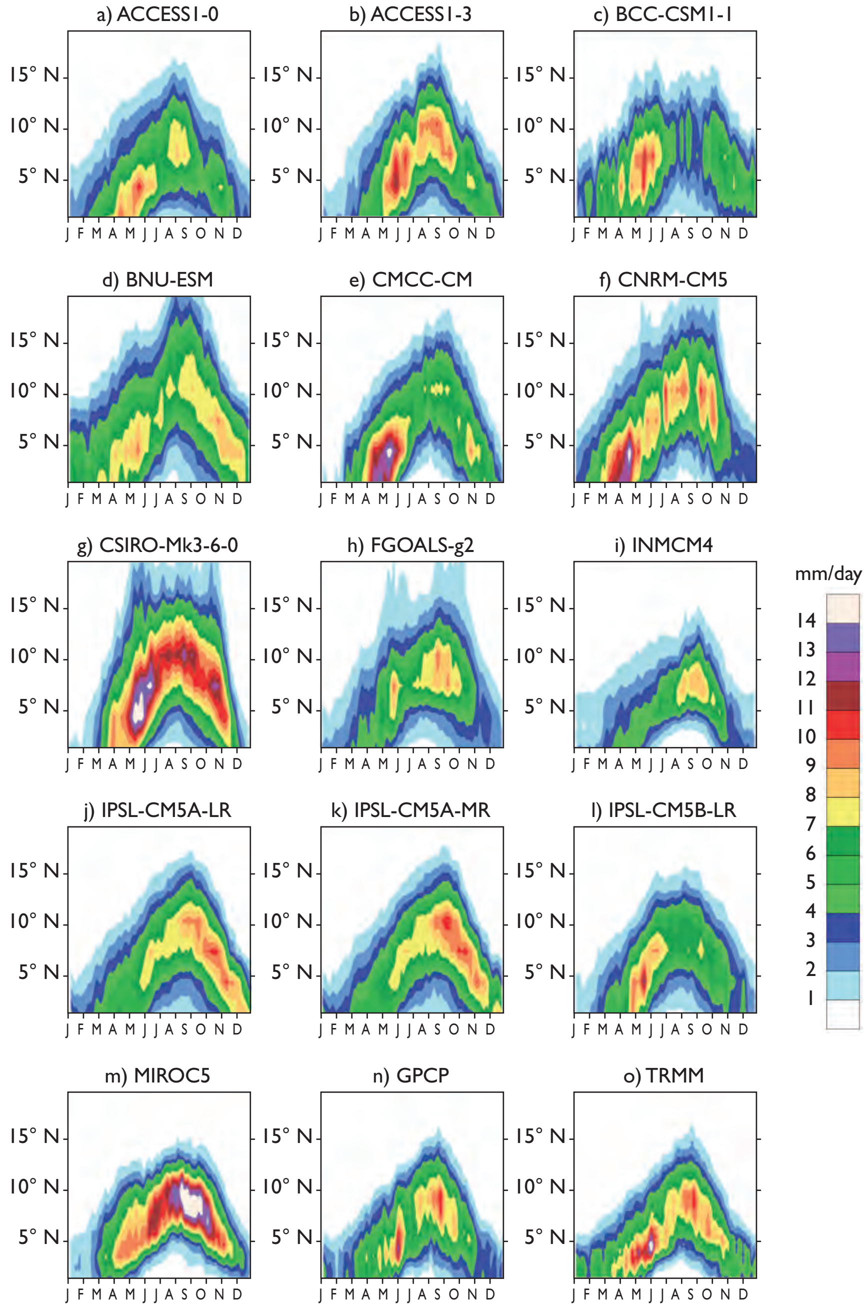

Figure 4.
1996-2008 seasonal evolution of mean precipitation
between 10°W and 10°E (in mm per day) given by CMIP5 models and GPCP observations.
The seasonal cycle has been smoothed by means of a 10-day sliding average.

show the onset of the monsoon sufficiently. Indeed 9 of the 13 models studied give poor coverage of the onset (BCC-CSM1-1, CMCC-CM), or a very staggered second phase, that is to say the rainy season in the Sahel (BNU-ESM), or a first phase (maximum rainfall on the Guinean coast) that is too far north (FGOALS-g2, MIROC5) or too weak (INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR). Finally, only the models ACCESS1-0, ACCESS1-3, CNRM-CM5 and CSIRO-Mk3-6.0 succeed in reproducing more or less the three phases of intra-seasonal variability of the WAM, with ACCESS1-0 and CNRM-CM5 performing less well.

What are the climate projections for West Africa in the 21st century?

The 4th IPCC report (CMIP3 simulations) concluded that global warming was very likely to occur as a result of the increase in greenhouse gases in the atmosphere (MEEHL *et al.*, 2007). However, there was a divergence between models in the precipitations in certain regions and in particular in the Sahel (COOK, 2008). The question is therefore that of knowing what progress has been contributed by the work of CMIP5, based on the 5th IPCC report.

Rainfall projections for West Africa in the 21st century

Figure 5 gives a succinct view of the changes in precipitation in West Africa in the 21st century in a so-called ‘realistic’ scenario, rcp4.5, for the period 2011-2040. Most of the CMIP5 models studied (8-10 out of 13) show for the coming 30 years rainfall projections that are rising in the Sahel east of 10° W, and falling west of 10°W (except for BCC-CSM1-1 and INMCM4) and falling in the Maghreb (except for ACCESS1-3, BNU-ESM, CSIRO-Mk3-6.0, FGOALS-g2, MIROC5). For equatorial Africa during the same period, most of the models (9 out of 13) show rising projections while the models BCC-CSM1-1, BNU-ESM, CSIRO-Mk3-6.0 and INMCM4 tend to show the opposite. The ensemble mean of the models studied displays rising rainfall projections for the Sahel (east of 10°W) and equatorial Africa and falling projections in the Sahel (west of 10°W) and the Maghreb.

For the second half of the 21st century (figure not shown) most of the models (ACCESS1-0, ACCESS1-3, BCC-CSM1-1, CNRM-CM5, FGOALs-g2, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5) confirm an increase in rainfall in the central and eastern Sahel, increased rainfall in equatorial Africa and a decrease in the western Sahel and the Maghreb (with a difference between the models in the Maghreb regions concerned). Two models (CSIRO-Mk3-6.0 and INMCM4) stand out for this period by projecting decreases in rainfall in practically

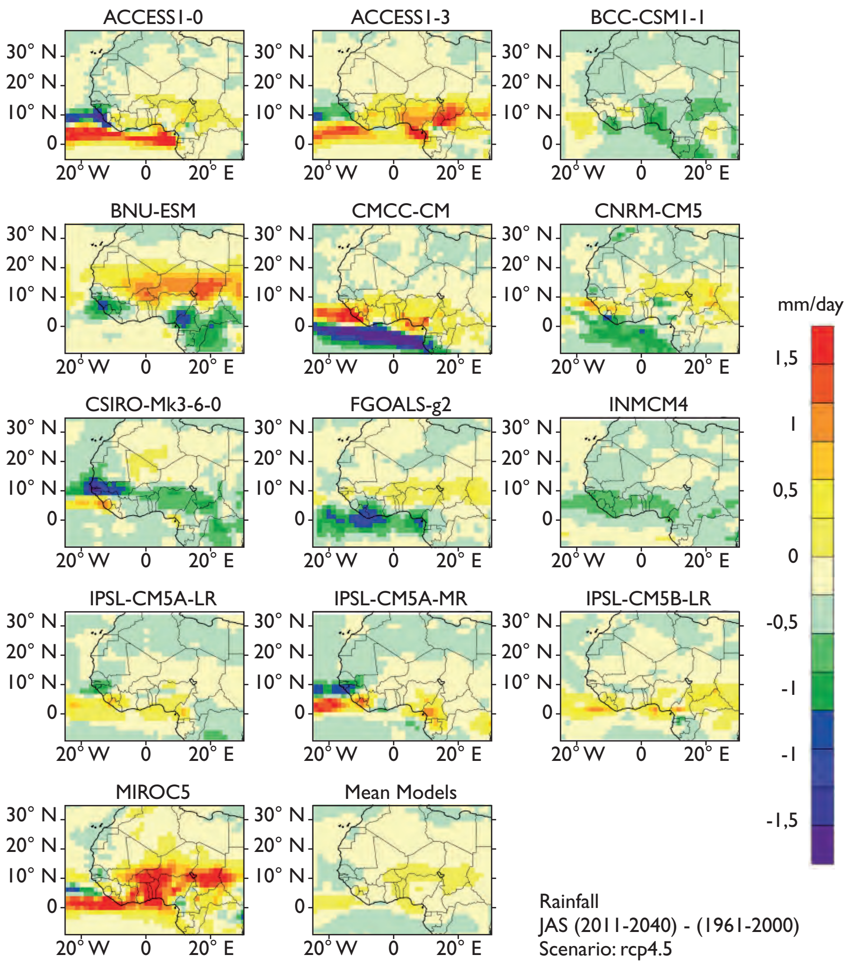

Figure 5.
The difference in rainfall between the future (scenario rcp4.5) and the present (historical) climate in West Africa in JAS (July-August-September) in 12 CMIP5 models and their ensemble mean for the period 2011-2040.

the whole of West Africa; two other models (BNU-ESM and CMCC-CM) give opposite results for the central and eastern Sahel and equatorial Africa. The last 30 years of the 21st century (2071-2100, figure not shown) confirm (in 10 models out of 13) upward rainfall projections in the eastern and central Sahel and in part of equatorial Africa and decreasing rainfall projections in the western Sahel and the Maghreb. The models do not agree clearly about the Maghreb. CSIRO-Mk3-6.0 and INMCM4 models also confirm their singularity by giving downward rainfall projections for the whole of West Africa, while the BCC-CSM1-1 model practically divides the continent in two: decreasing rainfall in the west and increasing rainfall in the east.

Scenario rcp4.5 shows, for the majority of the CMIP5 models studied, rainfall projections for the 21st century and during the July-August-September rainy season compared to 1961-2000: (1) an increase in the central and eastern Sahel, in part of the equatorial zone (0-10°N) and in the Maghreb; (2) a decrease in precipitation in the western Sahel, Gabon and the Congo (5°S - 0°).

Figure 6 shows the changes in precipitation in West Africa in the 21st century in comparison with present precipitation in the case of the 'pessimistic' scenario rcp8.5 for 2011-2040. Precipitation projections for the first 30-year period give markedly contrasted results. First, most of the models studied (BNU-ESM, CNRM-CM5, FGOALS-g2, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5) give increasing rainfall projections for the central and eastern Sahel and a decreasing projection for the western Sahel, while two models (BCC-CSM1-1 and CSIRO-Mk3-6.0) indicate the opposite. Then three models (ACCESS1-0, ACCESS1-0 and CMCC-CM) give rising rainfall projections for the entire Sahel while two others (INMCM4 and IPSL-CM5B-LR) tend to indicate a decrease. For equatorial Africa, more than half of the models studied (BCC-CSM1-1, BNU-ESM, CSIRO-Mk3-6.0, FGOALS-g2, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR) show decreasing rainfall projections while five models (ACCESS1-0, ACCESS1-3, CMCC-CM, CNRM-CM5, MIROC5) indicate the opposite. Finally, almost all the models studied (except for MIROC5) give decreasing rainfall projections for the Maghreb even if they are not in agreement about the zones concerned.

Only one model (FGOALS-g2) makes increasing rainfall projections for the entire Sahel for the second half of the 21st century (2041-2070; figure not shown). A single model again (CSIRO-Mk3-6.0) differs by giving decreasing rainfall projections of more than 1.5 mm per day for the entire Sahel. A large majority of the models (ACCESS1-0, ACCESS1-3, BCC-CSM1-1, BNU-ESM, CMCC-CM, CNRM-CM5, CSIRO-Mk3.6.0, FGOALS-g2, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5), that is to say 10 out of 13, give decreasing rainfall projections in the western Sahel and increasing projections in the central and eastern Sahel. In this category, two models (BCC-CSM1-1 and INMCM4) give greater extension in the western Sahel concerned by a decrease in precipitation: this covers an area from Niamey (2.5°E) to Senegal. The projections of almost all the models indicate a decrease in rainfall in the Maghreb, although some of these models (ACCESS1-3, BNU-ESM, CNRM-CM5, FGOALS-g2) exclude Algeria and eastern Morocco. For the southern part of equatorial Africa (Gabon, Congo and the Democratic Republic of the Congo), 8 out of 13 of the models (ACCESS1-0, BCC-CSM1-1, BNU-ESM, CSIRO-Mk3-6.0, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR) project a decrease in rainfall. However, the projections of several models (ACCESS1-3, CMCC-CM, CNRM-CM5, FGOALS-g2, MIROC5) tend to indicate an increase in rainfall in the above zone.

The projections of the models for the last decades of the 21st century (2071-2100; figure not shown) show broad agreement on a decrease in precipitation in the Maghreb: only the model BNU-ESM indicates the opposite. It is true that some models (CNRM-CM5, FGOALS-g2, MIROCS) also indicate a decrease in the eastern Maghreb and in Libya. The projections of a great majority of the models

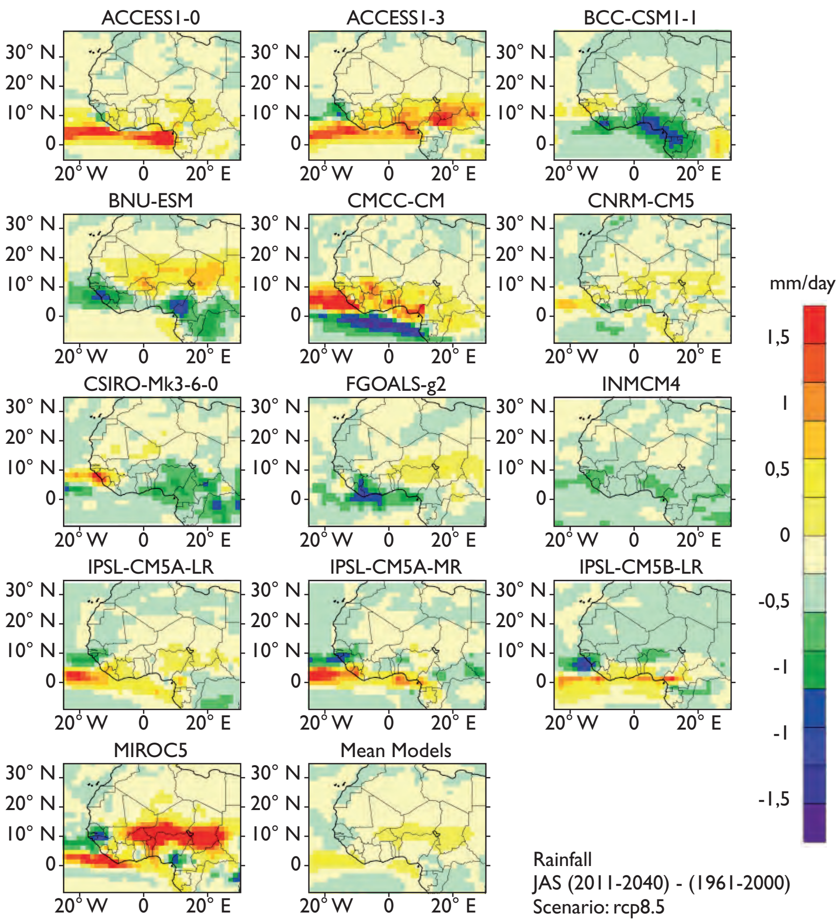

Figure 6.
Difference in rainfall between the future (scenario rcp8.5) and the present (historical) climate in West Africa in JAS (July-August-September) in 12 CMIP5 models and their ensemble mean for 2011-2040.

(ACCESS1-0, ACCESS1-3, CMCC-CM, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5) show a decrease in rainfall in the western Sahel and an increase in the central/eastern Sahel. For this period there are also models (BNU-ESM, CNRM-CM5, FGOALS-g2) that give projections for increased rainfall throughout the Sahel and two models (BCC-CSM1-1 and CSIRO-Mk3-6.0) that project the opposite. Finally, for the south of equatorial Africa (Gabon, Congo and the Democratic Republic of the Congo), a large majority of the models (ACCESS1-0, ACCESS1-3, BNU-ESM, CSIRO-Mk3-6.0, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR) gives projections for a decrease in rainfall, while three others (CMCC-CM, CNRM-CM5, FGOALS-g2) indicate the opposite. Two models (BCC-CSM1-1 and CSIRO-Mk3-6.0) stand out for this zone by giving opposite projections for the Guinean coast and the south of equatorial Africa.

In an rcp85 scenario, the ensemble mean of the CMIP5 models studied show rainfall projections for the 21st century for the July-August-September rainy season compared to the period 1961-2000. This shows (1) an increase in the eastern Sahel, with very high figures for Burkina Faso, southern Niger, southern Chad and the Sudan towards the last decades of the 21st century, (2) a decrease in the western Sahel (Senegal, the Gambia and Guinea) and figures becoming very high towards the final decades of the century in the Casamance, the Gambia and the whole of Guinea; (3) a decrease in the Gabon, the Congo and the Democratic Republic of the Congo (in the southern part of equatorial Africa); (4) a decrease in the Maghreb affecting the whole of Morocco in the first period and remaining in the northern part of the zone (Morocco, Algeria, Tunisia and Libya) towards the last decades.

Temperature projections for West Africa in the 21st century

July-August-September rainy season projections for the 21st century are compared to the period 1961-2000, in an rcp4.5 scenario (figure not shown): temperatures rise in West Africa in almost all the models. Only one (BNU-ESM) gives downward temperature projections—throughout the 21st century—for the central Sahel. This model is joined by FGOALS-g2 for the period 2071-2100. The projection of rising temperatures divides West Africa into two zones: (1) north of 12.5°N where the temperature difference is 2°C for the first 30 years, reaching some 2.5°C towards the end of the 21st century; (2) south of 12.5°N where the temperature difference is 1°C during the period 2011-2040 and then reaches 2°C in 2071-2100.

In a pessimistic scenario rcp8.5, the projection of temperatures compared to those of the recent past is shown in Figure 7. Projections for the first period (2011-2040) give increases reaching 2.5 -°C-3°C north of 15°N in all the models and 1°C for all the models (except for BNU-ESM that tends to give downward temperature projections in the central and eastern Sahel) south of 15°N. This warming trend in projections is confirmed by all the models, both north of 15°N (where 3.5°C is reached) and south of 15°N (2°C) during the period 2041-2070 (figure not shown). However, in this southern part of the region the warming of the entire Guinean coast is distinctly more moderate. Finally, warming is accentuated in the final decades of the 21st century, accentuating the trend (figure not shown): this varies from 3°C south of 15° N (including the Guinean coast this time) to 4-5°C northwards.

A remarkable feature of these temperatures — even in an ‘unrealistic’ rcp2.6 scenario—is that the projections indicate rises in practically the whole of West Africa (except for Libya and part of northern Niger, Mali and Chad) of as much as 0.5°C during the ongoing decades 2011-2040 (figure not shown). Furthermore, this upward trend should reach 1°C at the end of the 21st century and concern the whole of West Africa. This has led us to focus on the dry season as Fontaine *et al*. (2013) showed recently that an increase in heatwaves could occur then (see also Chapter 1).

This is why we show in Figure 8 the temperature projections for March-April-May in comparison with present temperatures (1961-2000) for a scenario considered to be realistic, that is to say rcp4.5. Increases of up to 1.5°C are observed in 2011-2040

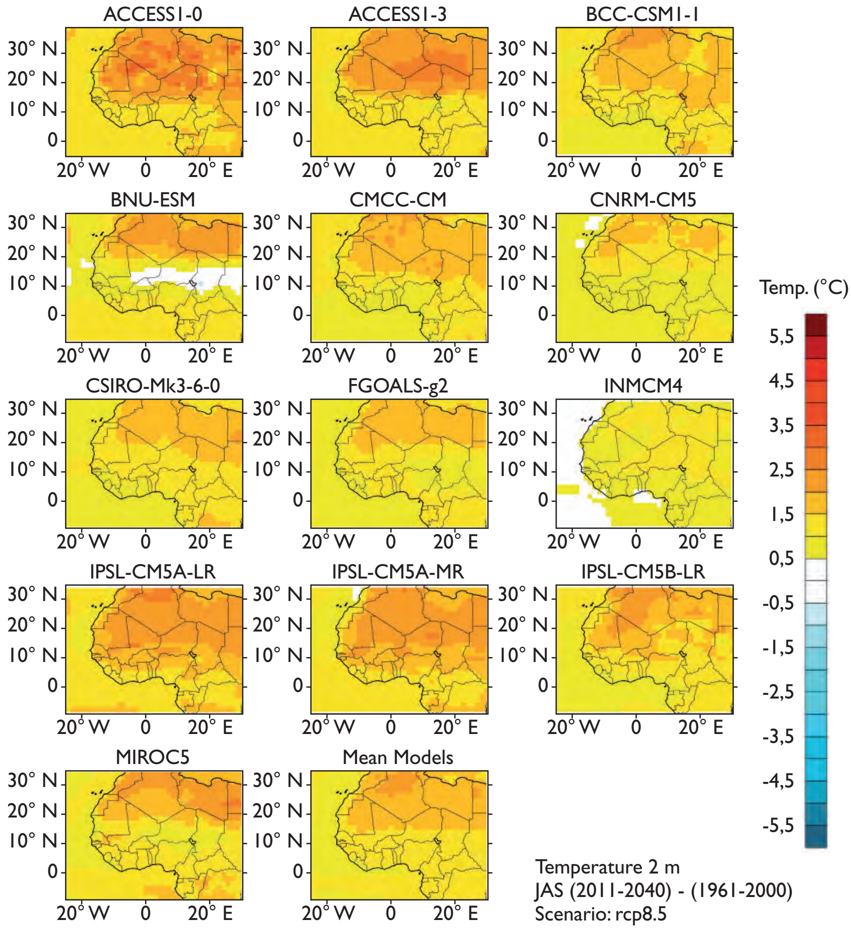

Figure 7.
The difference in temperature between the future (scenario rcp8.5) and the present (historical) climate in West Africa in JAS (July-August-September) in 12 CMIP5 models and their group average for the period 2011-2040.

in part of the central and northern Sahel (Algeria, Niger, northern Burkina Faso, Mali and northern Senegal), with agreement between the models examined (Fig. 8a). The increase is accentuated in the second half of the 21st century (figure not shown) reaching 2°C everywhere in West Africa and exceeding this in Algeria, Niger and Mali. Finally, the end of the 21st century will be marked by an acceleration of this rising trend (with 2.5°C exceeded everywhere in northern West Africa) and its spread as far as the southern part of the continent to about 10°N, thus affecting Guinea, Côte d'Ivoire, the whole of Burkina Faso and even northern Nigeria (Fig. 8b). These results conform the relevance of the questions raised by the ACASIS project in the analysis of heat wave phenomena during the dry period in West Africa.

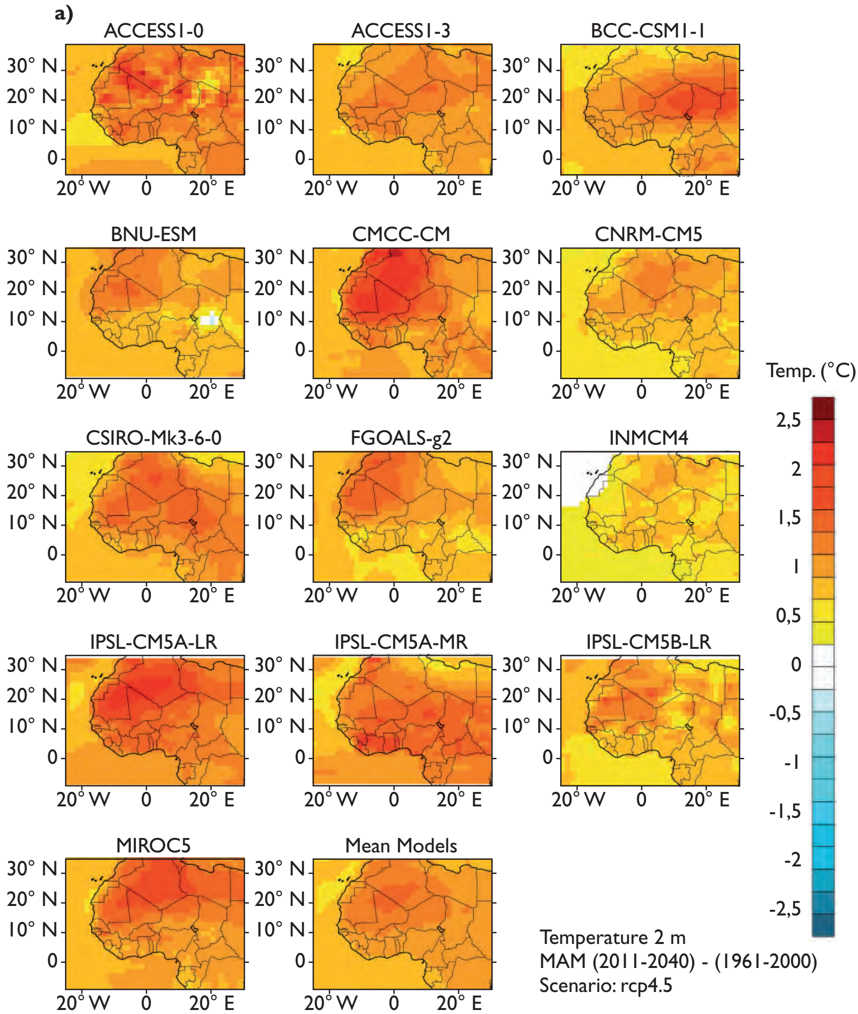

Figure 8a.
Difference in temperature between the future (scenario rcp4.5)
and the present (historical) climate in West Africa
in MAM (March-April-May) in 12 CMIP5 models
and their group average for the periods 2011-2040.

The precipitation projections are different for the Sahel between the west (15°W-5°W) with a decrease and the east (10°E-35°E) with an increase and a transition zone (5°W-10°E) in which the models diverge. In contrast, as regards temperatures, warming seems to be solid and display considerable amplitude. Likewise, the warming is so great in the dry season that the occurrence of frequent heatwaves is very plausible, as is mentioned in the 5th IPCC report (see also Chapter 1).

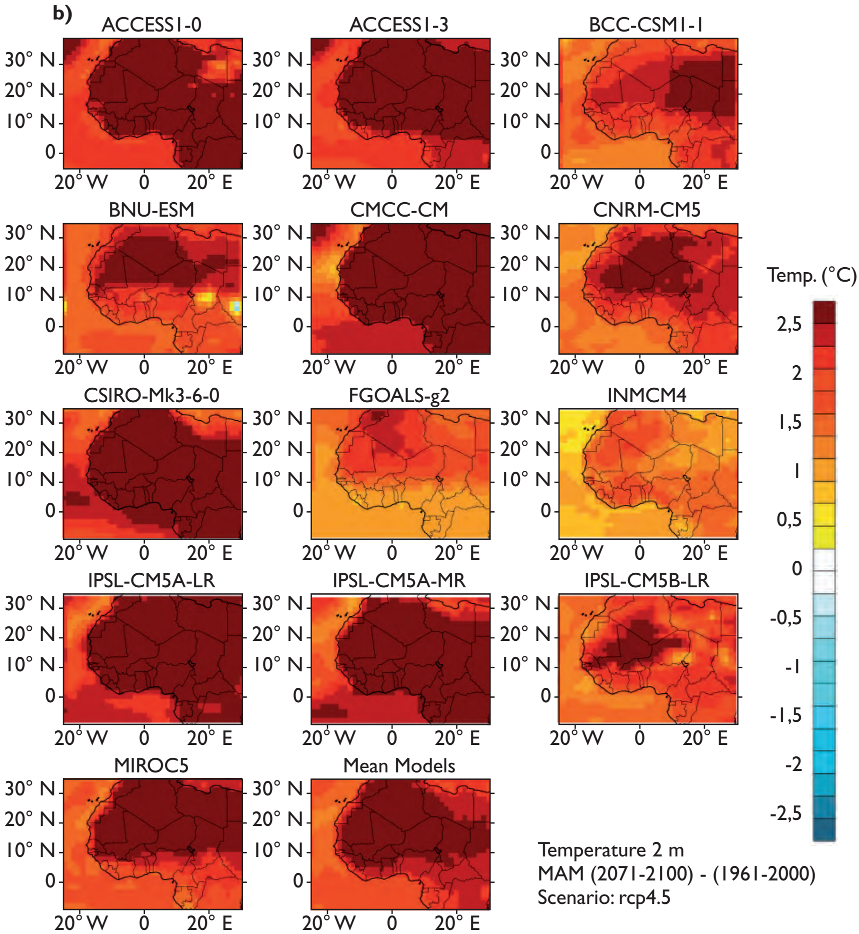

Figure 8b.
Difference in temperature between the future (scenario rcp4.5) and the present (historical) climate in West Africa in MAM (March-April-May) in 12 CMIP5 models and their group average for the period 2071-2100.

What are the obvious features and uncertainties of climate projections for the 21st century in West Africa?

The results of the CMIP5 models examined and analysed in the first paragraph show that they give a reasonable picture of certain key features of the WAM. Confidence can therefore be awarded to these models for their ability to provide more or less reliable climate projections for West Africa. The results above seem to show that confidence in the models would be higher for temperatures than for precipitations.

The aim in this paragraph is to reply to this assertion by evaluating—for both parameters—which results are robust and, for results that are not robust, to see what uncertainties are associated with them. For this, we first designed simple diagnoses inspired by ROEHRIG *et al*. (2013) to compare the means of all the models, their dispersion and their agreement of these scales. We then took the characteristic regions of West Africa where the results seemed to diverge and determined the evolution during the 21st century of the mean values of anomalies in precipitation and temperature, together with their dispersion.

Precipitation

Figure 9 shows the mean changes, spread and sign consistency between models for rainfall in JAS, for scenario rcp4.5 and for the periods 2011-2040 (9a), 2041-2070 (9b), 2071-2100 (9c), for scenario rcp8.5 and for the same periods respectively (fig. 9d, 9e et 9f).

The ensemble mean of the models with an rcp4.5 scenario indicates an overall increase in precipitation during the period 2011-2040, in the eastern Sahel (from Chad to Bamako, towards 10°W), a decrease in the western Sahel (from Bamako to Senegal) and a decrease in the Maghreb (Morocco, Tunisia and northern Libya). Very marked variations are seen in standard deviation (Fig. 9a), reaching 2-2.5 mm per day, especially in the Gulf of Guinea as far as Liberia and Sierra Leone, thus showing considerable uncertainty with regard to this increase in rainfall. Agreement between models with regard to the increase in the Sahel reaches 80%, whereas that for the western Sahel varies from 60% (south Senegal and Guinea-Bissau) to 40% (Bamako-Senegal). Agreement as to the decrease in precipitation is weak (30-40%) in the Maghreb as well. No noteworthy changes in ensemble mean and dispersions in models in the Sahel are noted in an rcp8.5 scenario (Fig. 9d). In contrast, agreement among models changes in the eastern Sahel: it stays at 80% in the most easterly part (Niger-Chad) but decreases to 40-60% in Burkina Faso and Mali and to 40% in the western Sahel.

Few changes are observed in the ensemble mean in the half of the 21st century and in an rcp4.5 scenario (Fig. 9b), except for the spread of the decrease in the Maghreb (reaching Mauritania, Algeria and almost the whole of Libya) and its accentuation in the Casamance and Guinea. However, an increase in dispersion in the eastern Sahel and a change in the agreement between models in this zone are noted. Agreement remains strong (80%) in Niger and Chad but decreases strongly (40-60%) for Bamako-Niger; in contrast, it increases in the western Sahel, reaching 50-60% in a large part of Senegal and 40-60% in the northern Maghreb. The rcp8.5 scenario (Fig. 9e) confirms the increase in agreement for Senegal (60%) and in much of the Maghreb.

Rainfall projections for the mean of all the models tend to display a decrease in precipitation in the Maghreb at the end of the 21st century in an rcp4.5 scenario (Fig. 9c) but vary very little for the Sahel in comparison with the beginning and middle of the 21st century. However, agreement between models decreases in the eastern Sahel (Niger-Chad) while remaining fairly high (60%). In contrast, it remains

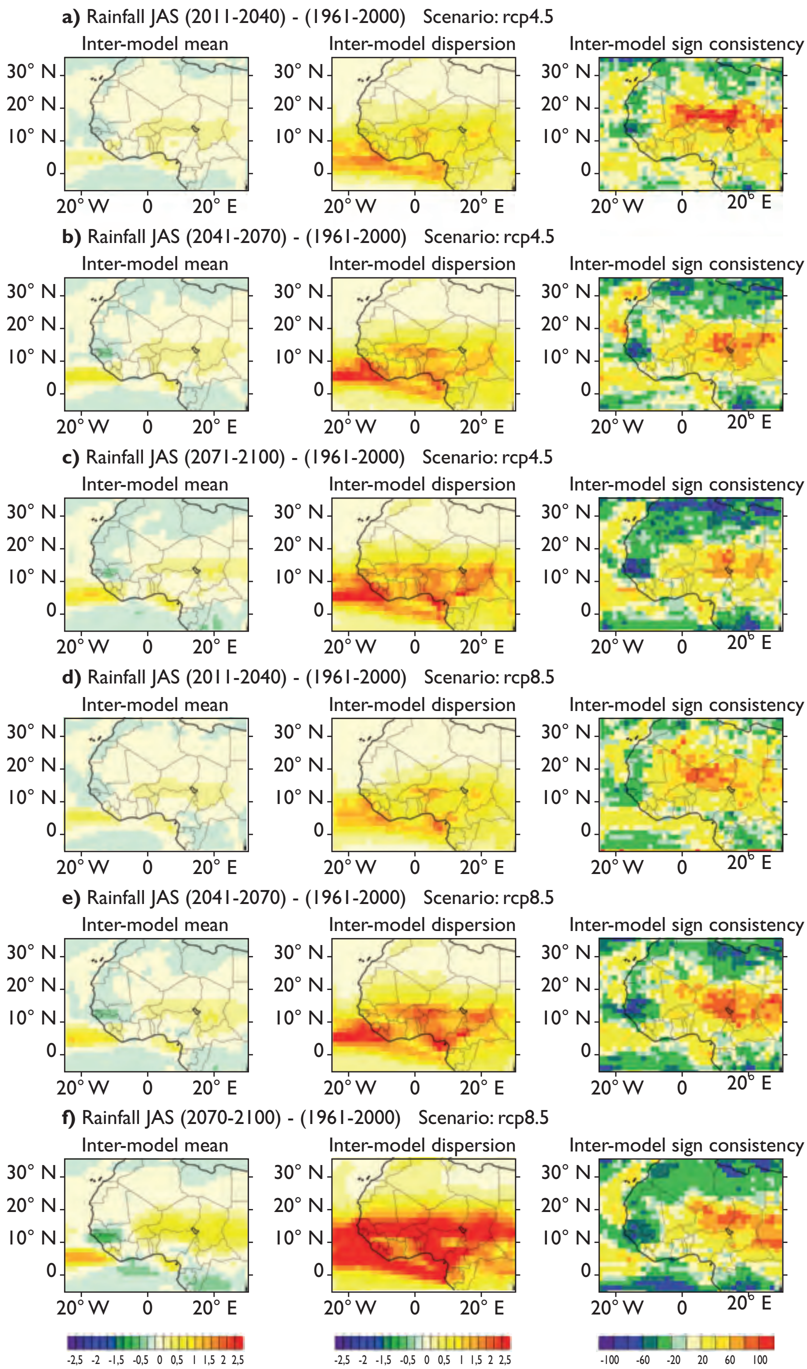

Figure 9.
Ensemble mean, spread and sign consistency of the CMIP5 models in the evolution of rainfall in JAS, for scenario rcp4.5 and the periods 2011-2040 (a), 2041-2070 (b) and 2071-2100 (c) (d-f for scenario rcp8.5).

stable in the western Sahel and the Maghreb, but covers the whole of these areas, unlike the case in the preceding period. Dispersion increases considerably in the Sahel, reaching 2.5 mm per day almost everywhere in an rcp8.5 scenario (Fig. 9.f). But agreement on the difference in rainfall divides the Sahel into three zones: the west (15° W-5° W) with 40-60% of the models, the centre (5° W-10° E) with few models (20-30%) agreeing with each other and the extreme eastern part (10° E-30° E) with agreement between 60-80% of the models.

The following features of these results seem obvious in the two scenarios studied: (1) differences in the Sahel for rainfall projections in the 21st century, with a western part (Bamako-Senegal) displaying a decrease in precipitation and an eastern part (10° E-30° E), from Niger to the Sudan, with a somewhat opposite trend; (2) the special case of a transition zone from 5°W to 10°E (Bamako to the centre of Niger), where the models do not display clear agreement with regard to the decrease in precipitation.

Temperatures

Figure 10 shows the ensemble mean, inter-model dispersion and agreement between models for the variation of temperature in JAS in scenario rcp4.5 for the periods 2011-2040 (10a), 2041-2070 (10b) and 2071-2100 (10c) and for scenario rcp8.5 for the same periods (Fig. 10d, 10e and 10f). The results seem robust for rcp4.5 and the three periods covered and feature warming everywhere, accentuated north of 15°N in the first period and even reaching 10°N in the middle and at the end of the 21st century, with levels always greater than 2°C (Fig. 10a-c). Likewise, projection dispersions are broad (from 1.5°C in the first decades to 2.5°C in 2041-2071) in a Sahelian strip between 10° N-20° N and 0°-30° E. This dispersion is less marked in this strip in the western part of the continent (15° W - 0°). The warming observed is common to the models except in zones of broad dispersion but where agreement between the models nevertheless exceeds 80%. The configurations are similar in an rcp8.5 scenario (Fig. 10d-f) but with an almost doubling of warming in comparison with the figures of the rcp4.5 scenario.

For discussion of projection uncertainties, we therefore considered the zones identified as having broad dispersions in the models (rather than examining West Africa as a whole). Annual mean anomalies were calculated (in comparison with the 20th century) in rainfall and temperature projections with their dispersions.

Figure 11 shows the evolution in time from 1900 to 2100 of the annual temperature and precipitation anomaly of the ensemble mean of the twelve MIP5 models studied in the western Sahel for the rcp4.5 and rcp8.5 scenarios. Warming in a cp4.5 scenario seems to have been distinct since the 1980s, reaching nearly 1°C in 2010, almost doubling in 30 years before stabilising at about 3°C towards 2070 (Fig. 11a). The uncertainty with regard to this warming (+/- 0.2°C) is fairly small in the 2010s and then increases very rapidly to +/- 1.2°C towards the end of the 21st century. In an rcp8.5 scenario (Fig. 11c), warming is practically identical to that of the rcp4.5 scenario until 2040 when it reaches 2.5°C (2°C in the rcp4.5 scenario) but then increases very rapidly: it is 4°C in 2070 and then 6°C at the end of the 21st century.

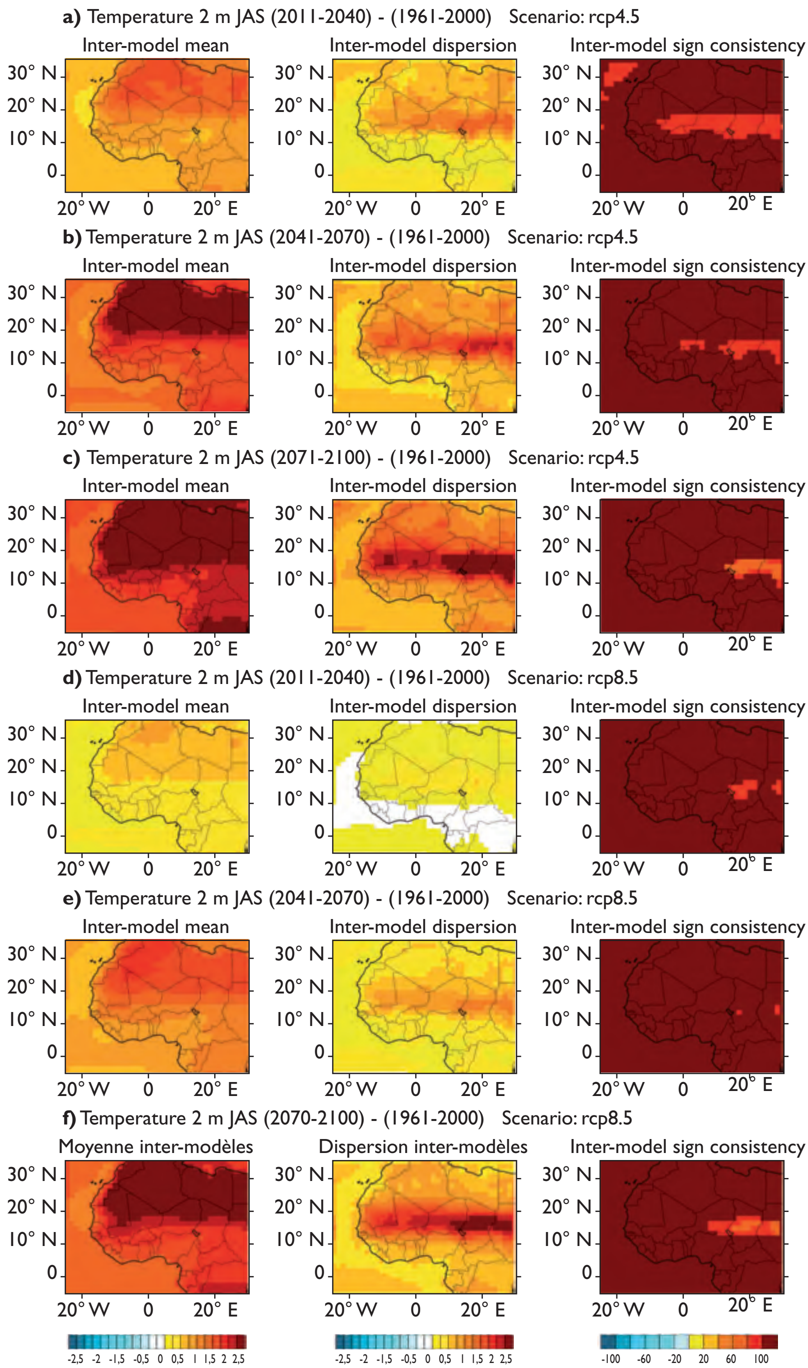

Figure 10.
Ensemble mean, spread and sign consistancy of the CMIP5 models
in the evolution of temperature in JAS, for scenario rcp4.5
and the periods 2011-2040 (a), 2041-2070 (b) and 2071-2100 (c) (d-f for scenario rcp8.5).

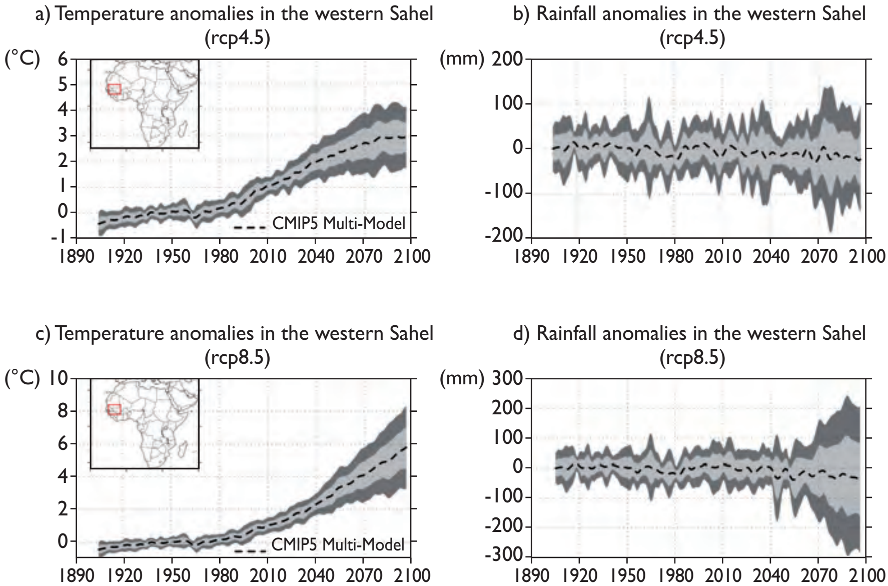

Figure 11.
Evolution of the temperature anomaly (a, c) and of the rainfall anomaly (b, d) of the mean of all the CMIP5 models studied between the 20th century and the 21st century in the western Sahel zone (10-20° N, 15° W-5° W, indicated by a red rectangle), for the rcp4.5 and rcp8.5 scenarios.
The dotted lines represent the anomaly, the pale area represents 1-sigma and the dark area 2-sigma.

The uncertainty of this warming is much the same as in the rcp4.5 scenario until 2040, but it is more than double (+ /- 2.8°C) towards the end of the 21st century. A great difference between the warming in the rcp4.5 and rcp8.5 scenarios is that it stabilises from 2070 in the first case but continues to increase fairly rapidly in the second. Although it is variable, the rainfall anomaly in an rcp4.5 scenario (Fig. 11b) is generally positive from the beginning of the 20th century until the 1970s, when it becomes negative—coinciding with the Sahel drought. After a slight return to positive anomalies towards 2010, a decrease in precipitation tends to take shape, lasting until the end of the 21st century. This rainfall anomaly range fluctuates around +/- 80 mm in 2040-2070, reaching +/- 120 mm towards the end of the 21st century. In an rcp8.5 scenario (Fig. 11d), the rainfall anomaly is slightly positive but with strong variability for 1990-2010. It then becomes negative again from 2040 until the end of the 21st century. The amplitude of variations is distinctly greater than that of the rcp4.5 scenario, varying between +/- 90 mm in 2010-2040, between +/- 120 mm in 2040-2070 and between +/- 230 mm in 2070-2100.

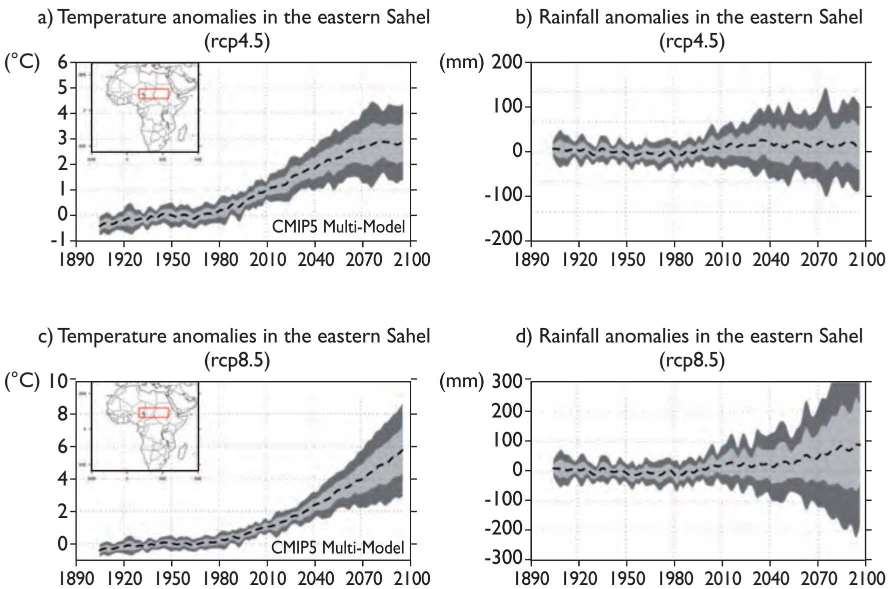

Figure 12.
Evolution of the temperature anomaly of the mean of all the CMIP5 models studied, covering the 20th and 21st centuries in the eastern Sahel zone (10-20° N, 10° E-35° E; indicated by a red rectangle), for the rcp4.5 and rcp8.5 scenarios.
The dotted lines represent the anomaly, the pale area represents 1-sigma and the dark area 2-sigma.

From 1980, warming is just as distinct in the eastern part of the Sahel in an rcp4.5 scenario (Fig. 12a) and displaying practically the same evolution as in the western zone. However, variation amplitudes are slightly greater at +/- 0.8°C towards 2040 (against 0.6°C for the west) and +/- 1.4°C from 2070 (against 1.2°C). In an rcp8.5 scenario (Fig. 12c), the evolution of the temperature anomaly is very similar to that of the western zone. However, variation amplitudes are slightly greater. The rainfall anomaly in the eastern Sahel in an rcp4.5 scenario displays an upward trend from the 1990S until 2040 (Fig. 12b), with strong variability. From 2040, although it remains positive, the rainfall anomaly oscillates around 30 mm until the end of the 21st century. The amplitude of variations increases very rapidly from 2000, oscillating around +/- 140 mm in 2040 (+/- 100 mm in the western zone) reaching +/- 160 mm towards 2100 (against +/- 120 mm). The amplitude of the variation of the rainfall anomaly in the eastern zone is thus distinctly greater than that in the western zone. In an rcp8.5 scenario (Fig. 12d), the increasing rainfall trend is greater and faster from 2040 (30 mm), reaching 100 mm towards 2100. The amplitude of variations (+/- 140-300 mm) is distinctly greater than that of the western zone during the same periods.

Conclusion

The results of simulations using 12 models participating in the CMIP5 have show that although these models have made considerable progress in representing the features of the WAM, their climate projections for West Africa have advanced little in comparison with those of CMIP3. However, the indication of warming in West Africa seems strong, reaching a mean of 3°C in an rcp4.5 scenario and twice this figure in an rcp8.5 scenario, that is to say 10% to 60% greater than average global warming. The dispersion of projections given by the models, as in CMIP3, is always substantial for temperatures but marked above all for precipitation. Although models are practically unanimous with regard to temperature in the warming forecast, variations of amplitude of 1.8-4.2°C in an rcp4.5 model and 3.5-8.5°C in the western Sahel (15° W-5° W) are reached; the figures are slightly higher in the eastern Sahel (10° E-35° E). This uncertainty with regard to the amplitude of variations of warming remains a large challenge to be taken up for the health implications involved. For precipitation, the projections given by the models lead to more questions than answers. What seems to be abundantly clear is that precipitation decreases in the western Sahel and increases in the eastern Sahel. This observation for the western Sahel is common to an increasing number of models as the 21st century proceeds: 40% in 2011-2040, 60% in 2041-2070 and over 80% in the final period. In contrast, even though agreement between models is fairly close for the eastern Sahel, precipitation decreases by 80% in the first period to 70% in the last period. The rcp4.5 scenario seems to show oscillations around a mean value in both the east and the west (positive in the first zone and negative in the second) implying great inter-annual variability, while the rcp8.5 scenario shows a distinct upward trend in precipitation anomaly in the east, reaching 100 mm at the end of the 21st century. The amplitudes of the variations in precipitation are fairly large, ranging in the western Sahel between 80 and 120 mm in the rcp4.5 scenario and between 90 and 230 mm in the rcp8.5 scenario. These amplitudes are slightly greater in the eastern zone. The existence of a zone from 5° W to 10° E (covering western Mali, Burkina Faso, northern Nigeria and eastern Niger) is observed where agreement between the models is small with regard to changes in precipitation in the two scenarios.

In short, although the CMIP5 models studied can give a good picture of the essential features of the WAM, it seems difficult to use their precipitation projections to make direct use of them to anticipate climate changes and their impacts as regards rainfall. This does not seem to be the case for temperatures, for which signs found are robust.

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Chapter 4

Contrasting perceptions with climate change

Scientific observations in three West African contexts

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Introduction

In parallel with measures to reduce greenhouse gas emissions, climate change adaptation has become a major research subject in recent years. Based on anticipation and resilience mechanisms, adaptation is aimed at 'managing the inevitable; when reduction seeks to avoid the unmanageable' (TUBIANA *et al*., 2010). The study of perception is of major interest in particular in rural West Africa, where adaptation is more likely to be autonomous. Indeed, it is accepted that cognitive factors play a role in the adaptation process through the perception of changes, the perception of risks and the perception of adaptive capacities (HANSEN *et al*., 2004; GROTHMANN and PATT, 2005; WEBER, 2010). Normative information in questions of climate is clearly given by scientific expertise. However, learning about climate change from personal experience is a strongly shared experience and the resulting perceptions are often a prior condition for action (mitigation and adaptation), whether or not there has been access to scientific information.

Comparing perception and scientific observations is still a methodological challenge. Whether scientific knowledge or uninitiated knowledge is concerned, both are based on observation but involve very different tools for seeing reality and generalisation methods. As is underlined by WEBER (2010), perception is based on the weather at a certain moment and the memory of it that is conserved; this is of course very different to knowledge of climate, which is based on a statistical distribution of the terrestrial atmospheric conditions in a given region and for a given period.

Furthermore, the lay public observes the weather using their human senses and interprets an unusual or extreme situation in relation to its experiences, memory, beliefs and expectations. Its perceptions are also often moulded more by the impacts of the climate than by the climate itself (Reckien *et al*., 2012; Leclerc *et al*., 2013). Several studies have shown that farmers take harvest losses or soil degradation into account to evaluate changes (West *et al*., 2008; Osbahr *et al*., 2011). This is doubtless why quantification is partly considered to be useless in many cultures (Berkes and Kislalioglu Berkes, 2008). In contrast, for scientists a climatic anomaly is an objectified statistical event that deviates from long series of averaged and projected measurements.

The cognitive processes involved in the assimilation of perceived information and in that of learned information are also different. Learning about climate change through personal repeated experience is based on mechanisms involving sensitivity, tangibility and immediateness and the resulting interpretations concern associative and affective principles (Weber, 2010). Using the climate event as a base rather than risk—especially when this is small—perception is also more volatile as it may change when the danger becomes more rare or when its impacts are less serious. Conversely, learning using statistical description assumes an analytic and intelligible approach and requires a longer period of assimilation.

So far, comparatively few studies have approached the comparison of perceptions of climate change with scientific observations. Several studies conducted in various sub-Saharan contexts reveal a divergence between perception of changes and the precipitations observed (Meze-Hausken, 2004; Gbetibouo, 2009; Osbahr *et al*., 2011; Mertz *et al*., 2012). In Burkina Faso, West *et al*. (2008) showed satisfactory perception of the long-term decrease in precipitation observed since the 1970s but not of the recovery of rainfall that occurred at the end of 1990. Osbahr *et al*. (2011) and Simelton *et al*. (2013) studied the perception of changes related to the beginning and end, but here again it was not possible to establish convergence.

Authors have found several reasons that account for these divergences. The notion of ‘optimal rainfall’ in which the rainfall pattern is judged by farmers is put forward by Meze-Hausken (2004) and Osbahr *et al*. (2011). From this angle, the perception of changes in the climate would be based on the rainfall required to cover family needs rather than ‘real’ rainfall. This leads to the staggering of expectations. Other authors stress the fact that recent events may influence perception of long-term precipitation trends (West *et al*., 2008; Mertz *et al*., 2012.). Finally, a third explanation is related to changes in farming systems. According to this view, divergences can be explained by the difficulty to differentiate changes in the farming system from those of changes in the weather (Simelton *et al*., 2013).

Using these analyses, we examine the perception of recent climate changes by the people of West Africa and compare them with scientists’ observations. As the climate and its present dynamics are not uniform at the scale of the continental region, we focused on three countries in order to cover a broad range of geo-climatic zones. Niger, with three climate strata ranging from desert areas in the north to the beginning of the semi-arid zone in the south, is covered entirely and provides climate perceptions from all inhabited environments. The two other countries involve smaller zones and are both strictly rural. In Benin, the study was conducted in the north—in the Sudanian-Guinean zone. In Senegal, the pluviometric status of the area examined lies between those of the other two countries and is in a semi-arid tree savannah zone.

The light shed by these three contexts and all the areas where people live was used to assess, in comparison with scientific observations, the ability of populations to detect recent climate changes. We also try to understand how these populations succeed in perceiving the reality of the climate, in particular according to their social and professional features and determinations of their environment. The central hypothesis of this work is that individuals detect climatic changes better when they have strong links with their natural environment.

The context of the research

In Benin, the study was conducted in the Djougou local administrative area at the southern border of the Sudan-Guinea zone, where average rainfall is 1100 mm per year (Fig. 1a). Some 22% of Djougou village area is farmed and more than 50% of the land is savannah. The rest is forest (JUDEX *et al.*, 2008). The study zones cover a total of 155 km^2. Every household in the two transects was surveyed. These families live from rainfed agriculture on small areas. Mainly family labour is used; the majority of households are polygamous and large. The households studied possess an average area of 10 hectares. The study area runs along Route Nationale 6 on either side of the town of Djougou (fig. 1a)

In Senegal, the zone studied is the Niakhar population and health-monitoring unit. This is in a dry, semi-arid zone (cumulated rainfall 500 to 650 mm per year since the mid-2000s) between the towns of Fatick in the south and Bambey in the north (Fig. 1b). The study zone is in the groundnut area (centre-west part of Senegal) and covers 30 villages with a population of approximately 45,000 in 2013 and an area of 200 km^2. Average population density is 215 persons per km^2, with villages displaying densities approaching or exceeding 400 persons per km^2 (DELAUNAY *et al.*, 2013).

The farmers in this zone are entirely devoted to crop and livestock farming combined in a system that is exceptional in West Africa (PÉLISSIER, 1966; LERICOLLAIS, 1999). Fields are generally in flat areas with sandy, permeable soil that is easy to plough and loosen. However, these soils generally display low water-holding capacity and mediocre fertility, generally leaving at their edge a small proportion of low-lying zones with sandy-clayey soil (5 to 10% clay) with greater fertility and better water-holding capacity. However, this soil is less permeable and hardens quickly after the rains. Almost all the farms (95%) grow rainfed crops—mainly millet and groundnut—on small areas (a little less than 5 ha on average). Households are large (13 persons) and family labour is mainly used.

Figure 1.
a) Map of the north of the commune of Djougou (Benin)
showing the northern and southern transects
b) map of the observation zone in the district of Niakhar in the Fatick region in Senegal.
This observation zone incudes 30 villages.

The Nigerien national survey, used in our study for perceptions of climate, covers all the bioclimatic strata of the country from the desert zone in the north to the Sudanian-Sahel and Sudanian zones in the south (Fig. 2). Niger is a land-locked country with an area of 1,267, 000 km², three-quarters of which consists of desert. The southern fringe of the country, with more than 90% of the population, has the greater part of non-mining natural resources (salt, water, vegetation and fauna). The climate is Sahelian overall with distinction made between four climatic zones. The Saharan zone (65% of the country) with less than 100 mm of rainfall per year, the Sahel-Saharan zone (12.2% of the country) with 100 to 300 mm of rainfall per year, the Sahel-Sudanian zone (21.9% of the country) with 300 to 600 mm of rainfall per year and the Sudanian zone (0.9% of the country) where rainfall is greatest at over 600 mm per year.

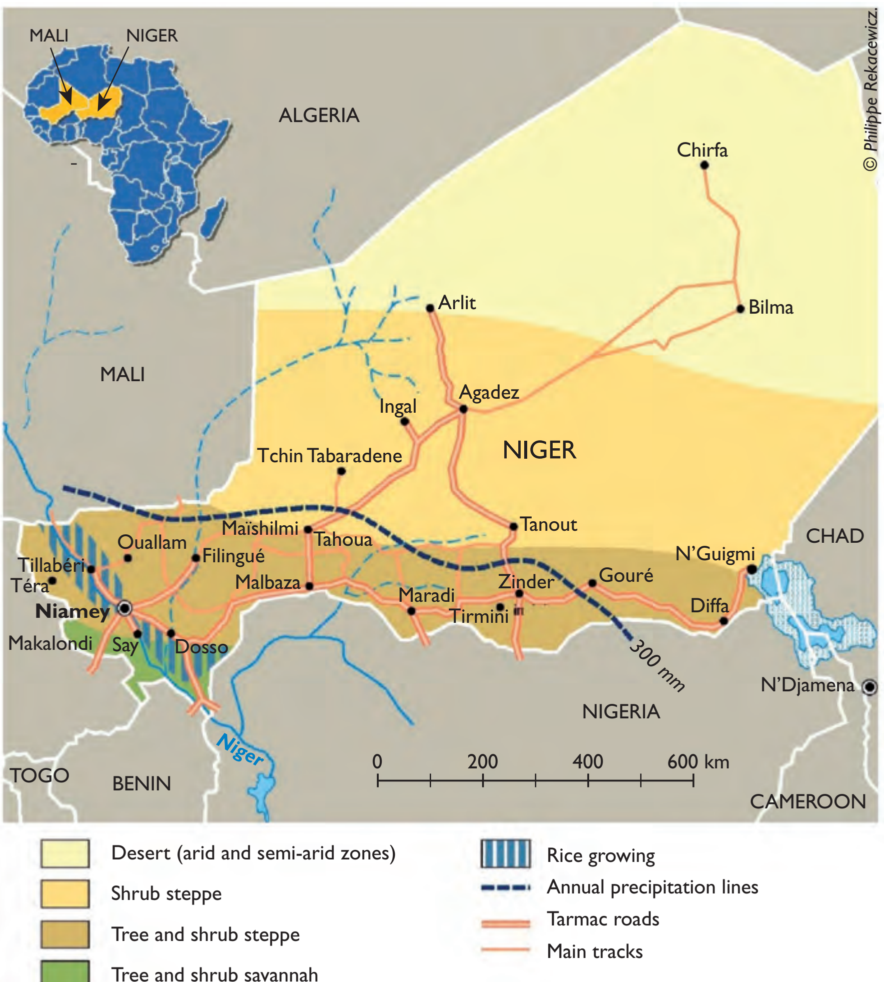

Figure 2.
Map of the bioclimatic zones of Niger.

Niger is one of the poorest countries in the world. The economy is based essentially on subsistence agriculture and livestock farming. Nearly 84% of the population lived in rural areas in 2010 and the primary sector employs nearly 87% of the population. Animal husbandry and crop farming are the second and third largest sources of income in Niger. Agriculture is found in the south in 15% of the country but involves nearly three-quarters of the national population. Most of Niger farming is on small farms with no mechanisation and sometimes with animal draught. Average farm size is 5 ha for 12 persons, of which 6 work on the farm. Millet, sorghum, cassava, beans and rice (the latter grown in river flood recession areas) are for local consumption. Cash crops (groundnuts and cotton) are found in the wetter southern zone. Animal husbandry is found in arid and semi-arid areas throughout the northern part of the country. It involves mainly cattle and sheep with transhumance for long distances.

Material and methods

Our comparison of the perception of the population and scientific observations of the climate is based on a questionnaire collected at local or national scales. This qualitative perception of the climate—old and recent—is then compared with temperature and rainfall figures from the meteorological and synoptic stations closest to the homes of the persons questioned (national networks). For sites where climate change is marked, analysis of the perceived climate is continued by the modelling of the factors associated with good perception by persons questioned in the survey.

Surveys were conducted in Benin and Senegal to appraise perceptions of climate, to define the social and professional characteristics of persons and the features of the environment that determine convergence with observed scientific data. The same protocol was used at the two sites (Niakhar in Senegal and Djougou in Benin). The surveys were performed between July 2013 and March 2014 in rural areas and using samples chosen at random from exhaustive survey bases: 1,102 households in Benin and 1,065 in Senegal. Two questionnaires were used for each household surveyed—the first for the head of the household and the second for a farmer chosen at random among those in the household that had cultivated a field during the three preceding years. This person could be the head of the household. The data used in Niger were those of the *Enquête nationale sur les conditions de vie des ménages et sur l'agriculture* (National Household Living Conditions and Agriculture Survey) (ECVM/A-2011) conducted from July 2011 to January 2012. Available free of charge, the data are drawn from the LSMS-ISA project implemented by the World Bank in collaboration with the Institut National de la Statistique of Niger (http://go.worldbank.org/V0810DTAC0). The sample was designed to be representative at national and regional levels and for agricultural, agropastoral and pastoral zones. The survey used a random two-stage sampling of 4,045 households in both town and country.

In Benin and Senegal, the ‘household’ questionnaire submitted to the head of the farm was designed to collect data on farming practises during the preceding rainy season. It also provides information about the economic status of the household, activities other than farming and the sociocultural characteristics of the head of the household. The ‘individual’ questionnaire was focused on certain cash crops such as groundnuts and watermelon and on beef fattening. More than 25 questions concerned perceptions of the present climate (during the preceding 10 years) and the past climate (20 years ago) and knowledge of climate change. These questions provided information about perceptions of the levels, calendars and evolution of rainfall, temperature and wind. In Niger, the household and crop/livestock questions were divided into 13 and 8 sections respectively. The crop/livestock sections of the questionnaire were focused on questions of access to land, farming systems (rainy and dry seasons), livestock, forestry, agricultural equipment and inputs and climate change. The latter section consisted of 11 questions on the climate as perceived during the previous five years and 13 questions on the farming strategies implemented because of perceived changes in temperature and rainfall. The environment of residence and the type of professional activity are used in the survey to check that the accuracy of perception of the climate depends on the links between persons and their environment.

An explanatory climate perception model was developed using data from the Senegal survey and completed by routine data collection at the Niakhar observation site. Data analysis was performed in two stages. The first consisted of establishing a perception indicator and a number of predictors. Perception of the climate is considered to be ‘good’ if the replies to the climate survey match the observations made over the last 10 years. If the description of the climate is accurate for at least 7 of the 8 criteria below, the farmer is considered to have a good perception of the climate. In the last 10 years, the climate should display the following pattern:

− increased rainfall;

− a longer rainy season;

− a late start of the rains;

− a late end of the rains;

− strong variation in rainfall from one year to the next;

− an increased number of violent heavy rainfall events;

− increased maximum temperature;

− increased minimum temperature.

The average duration of seasonal migration and the caste that persons belong to (guelwars, farmers, craftsmen and griots) are two indicators constructed by processing demographic monitoring data (Niakhar observation site). The other variables are from the survey using a questionnaire (ESCAPE-Senegal).

In order to check that Serer farmers in Senegal do not have identical perceptions of climate changes (although they are—overall—subjected to the same meteorological conditions and are all farmers), we evaluated the effect of their sociocultural and economic features on the accuracy of their perception of the climate. Among individual and household variables, the model uses 1) whether the respondent is a man or a woman, 2) his/her education; 3) the number of years of experience in farming, 4) the cumulated duration of seasonal migration during the last 10 years, 5) paid extra-agricultural work, 6) the caste of the respondent, 7) the ethnic group of the respondent, 8) membership of agricultural associations, 9) the use of meteorological information in his/her farming practices and 10) respondents living in a village in the north of the observation zone. The model was tested using binary logistic regression and STATA® 13. Finally, we refined the model (analysis of residues) by removing outliers and observation that weight on the model in an exaggerated manner (levers and influencing factors). The model thus edited explains 34% of variance and gives correct adjustment of the data (Hosmer-Lemeshow adjustment test).

Climate change in the region

As illustrated in chapters 1 and 2, West Africa has experienced major climatic upsets since the 1950s. In the Sahel in particular, Lebel and Ali (2009) showed that the great drought at the end of the 1960s triggered a long dry period that lasted for nearly three decades, followed by a recovery of rainfall in the last decade of the 20th century, although substantial regional disparities were observed (Chapter 2 of this book). Although very few studies have focused on the temperature changes in West Africa (Fontaine *et al.*, 2013), it is nonetheless clear that the temperature has increased considerably in the Sahel since 1950 (Chapter 1 of this book). Warming is distinctly greater at night than during the day as a result of the effects of water vapour, clouds and aerosols (Chapter 1 of this book). But it is important to set out these regional trends at a local scale characterising what African population feel and experience as regards climate. Changes in precipitation and temperatures observed since 1965 at the three survey sites in Benin, Senegal and Niger are shown in Figure 3.

Minimum temperatures expressed as annual means increased considerably at the three sites, with very positive linear trends, during the period 1965-2013. In 50 years, minimum temperatures have increased by + 1.2°C at Djougou, + 1.8°C at Bambey and + 1.4°C at Niamey, which is considerable. The trend is not as clear for maximum temperatures, even though an increase of nearly 1°C is seen at Djougou and Bambey. These results are strongly coherent with the observations for the Sahel as a whole (see Chapter 1).

Regional trends with abnormally dry conditions are observed at these three locations in West Africa during the 1970s and 1980s, followed by a wetter period. However, this general pattern includes noteworthy differences that cannot fail to influence perception of the climate by local populations. These differences include the observation that the driest years differ from one location to another: 1972, 1982 and

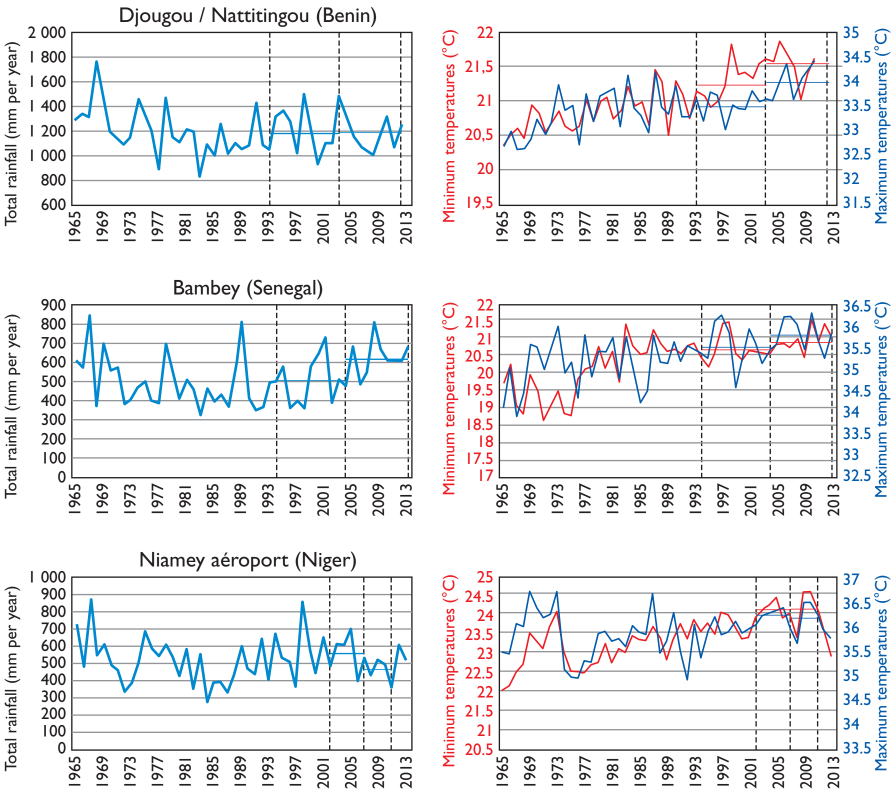

Figure 3.
Evolution of rainfall and temperatures observed since 1965
at the three survey sites in Benin, Senegal and Niger.
The vertical lines indicate the separation between two periods:
the present period preceding the survey and the historical reference period.

1984 in Niamey and 1977 and 1983 in Djougou, even if in the Sudanian-Sahelian context of Djougou it is difficult to talk in terms of drought as for Niger. It is also seen that the return of rainfall is observed in a very specific manner at each location. At Djougou, after a practically linear decrease from 1965 to 1983, rainfall increased rapidly and stabilised at around 1,200 mm per year from the beginning of the 1990s. No noteworthy change in cumulated rainfall for the last 20 years. The recovery occurred late at Bambey, with cumulated rainfall remaining small at around 450 mm per year between the early 1970s and the end of the 1990s and then increased rapidly, reaching an average of over 600 mm per year during the last 10 years, i.e. an increase of nearly 50% in 20 years. But in Niamey, although rainfall recovered after the great drought that lasted until the early 2000s, a significant decrease in cumulated annual rainfall has been observed during the last 10 years, even though there is still strong inter-annual variability.

Analysis of cumulated annual rainfall alone is not enough to show the reality faced by rural populations in the Sahel. The work by INGRAM *et al*. (2002) and by KLOPPER *et al*. (2006) showed that the most crucial variables for farming strategy in Africa are the start and the end of the rainy season, together with rainfall distribution within the monsoon season (intra-seasonal distribution). Indeed, the choice of sowing date is crucial in the strategy of a farmer who must be sure that sowing will not be followed by too long a dry period and that the crop reaches maturity at the end of the rainy season. In addition, a dry period during the critical phases of crop development can have serious repercussions on yield, even if cumulated rainfall for the season (total rainfall during the monsoon season) is substantial.

Analysis of the evolution of the features of the rainy season (beginning, end, length, number of days of rain, dry intervals) was conducted for each of the three locations for comparison with perceptions by the population (Table 1). Only the analysis of start of the rains is illustrated in this chapter (Fig. 4). Numerous methods exist for determining the date of the start of the rains (MARTEAU *et al*., 2011; SULTAN *et al*., 2005) and can give different mean dates depending on the criterion or thresholds chosen. Here, we used the method described by LIEBMANN and MARENGO (2001) and recently applied in Africa by BOYARD-MICHEAU *et al*. (2013). The method has the advantage of relying on rainfall anomalies and not on thresholds, and can therefore be applied to the three regions, even if rainfall conditions are completely different. In Benin, where the method shows that the rains start on 1 May, recent data are lacking to analyse changes to the start of the rainy season. A significant correlation was noted for Bambey between cumulated rainfall and the date of the start of the rains (R = - 0.48), which means that 25% of annual rainfall variation is accounted for by fluctuations in the start of the rainy season. Particularly early starts have also been observed since 2008, accompanying the high cumulated rainfall recorded in recent years. In Niger, even if there is no significant correlation between the cumulated annual total and the start of the rainy season, as is also shown by MARTEAU *et al*. (2011), the rainy season has become increasingly late since beginning of the 1990s.

Table 1.
Synthesis of the evolution of rainfall at the three locations for recent years covered by surveys.
Daily data for recent years in Benin are lacking.
In Niger, where the surveys covered recent trends in the whole country, very similar conclusions were obtained by using satellite rainfall estimates (FEWSNET) with resolution of 0.1 degree.

	Cumulated annual rainfall	**Start**	**Finish**
Djougou (Benin)	Stable	*NA*	*NA*
Bambey (Senégal)	Increase since 1996	Early start since 2008	Late end since 2009
Niamey (Niger)	Decrease since 2005	Increasingly late seasons since 1991	Late end since 2007

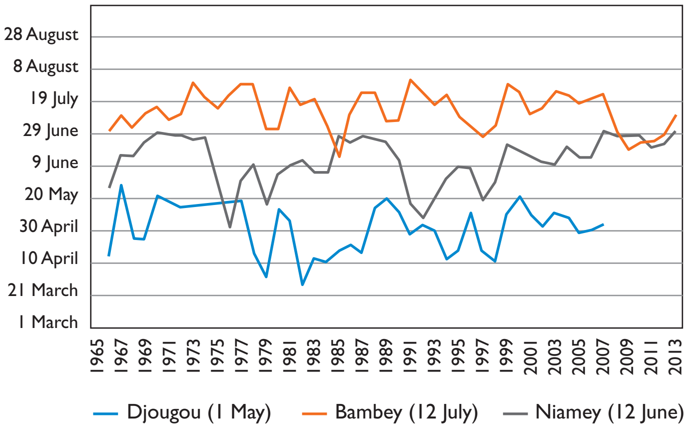

Figure 4.
Start of the rainy season in the three locations.
The figures are given as a 3-day sliding average.
The date in brackets is the average date of the onset of the monsoon during the period 1965-2013.

How do the populations perceive these changes?

Questioning the rural populations in the three countries about the recent trends in total rainfall (Fig. 5) reveals a good match between perceptions and rainfall observations, at least in Niger and Senegal where there have been substantial rainfall changes. In Niger, nearly 80% of the population surveyed said that they had perceived a decrease in rainfall in conformity with the deficit observed recently. In Bambey, the recent increase in rainfall had been perceived by more than 96% of the persons surveyed.

In Djougou, where the evolution of the climate is less marked and where rainfall has tended to remain stable in recent years, it is interesting to note that the opinions of the populations surveyed diverge, with nearly two-thirds of the persons surveyed considering that rainfall had decreased and nearly a third declaring the opposite. Only a very small proportion of the respondents at Djougou had perceived rainfall as being stable in recent years (2.4%). It is very probable that in the absence of a strongly marked trend as in Senegal and to a lesser degree in Niger, it is difficult to perceive stationary recent evolution, explaining the contradictory perceptions of residents of the Djougou area.

The populations surveyed in Senegal clearly perceived the transition observed between a dry period 20 years ago and the present wet period (Fig. 6). The drought – a major environmental problem for 65% of the population surveyed 20 years ago has now – has now become just a minor concern, with less than 3% considering it

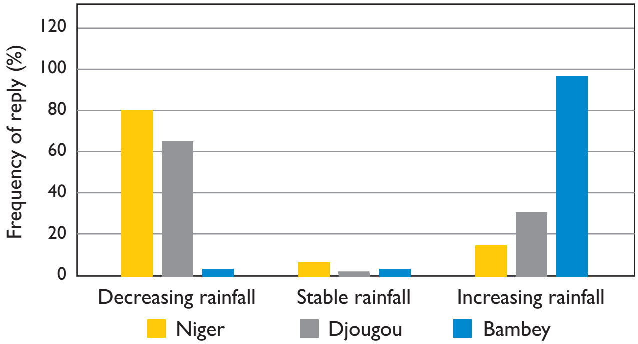

Figure 5.
Perception by rural populations of the recent evolution in cumulated rainfall. The results are shown as frequency of reply (%) for each of the three modes and for each of the three countries in which the surveys were conducted.

to be a problem affecting their area. The main concern today has become soil fertility, as highlighted by more than 70% of respondents. It is noted that the farmers in this part of Senegal are nearly three times as numerous to state that violent rainfall is currently a real environmental problem, in comparison with those who consider that this was already a major problem 20 years ago. The increased frequency of intense rainfall events is a phenomenon that has also been observed by climatologists.

The rural populations surveyed in Niger and Senegal also display excellent perception of the changes in the seasonal features of the monsoon. The lateness of the rainy season was perceived by 72% of the rural people surveyed, while the increasing earliness of the 'winter' was observed by 67% of the persons surveyed in Senegal. Most of respondents (65%) placed this change in the onset of the monsoon from 2008 to 2010, effectively corresponding to a period in which particularly early rainy seasons were recorded (Fig. 4). An earlier end to the monsoon was perceived by 81% of the rural population surveyed in Niger whereas a later end was observed by 72% in Senegal. These two perceptions corroborate pluviometric observations (Table 1).

This fairly close agreement between meteorological observations and the perceptions by populations in Senegal and Niger with regard to several pluviometric indicators (the evolution of cumulated rainfall, the period of the start and end of the rainy season, the frequency of intense events, inter-annual variability, etc.) is particularly remarkable. As a general rule, the literature finds the opposite in the arid and semi-arid zones of Africa: populations—including farmers whose living conditions depend on rainfed crops—do not perceive climatic evolutions as detected by scientists. Although the respondent populations questioned mentioned the inter-annual irregularity of cumulated rainfall, they never mentioned the return of rainfall observed in recent years (Chapter 2; Akopnikpè *et al.*, 2010; Mertz *et al.*, 2009, 2012; Diessner, 2012). The main changes felt by the populations are a decrease in annual rainfall, a shortening of the rainy season (later start and earlier end), an increase in dry periods during the rainy season and the existence of periodic droughts in certain

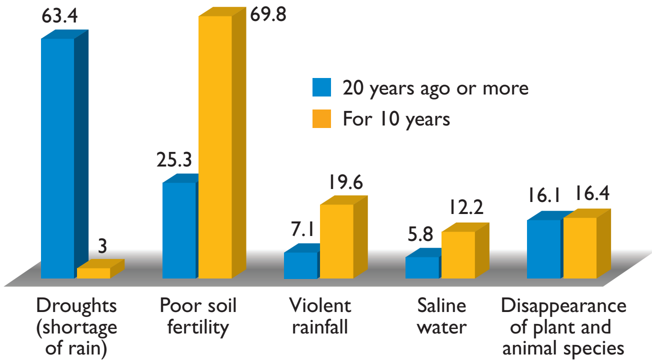

Figure 6.
The main environmental problems perceived by the populations survey in Senegal.
Only those mentioned by more than 5% of the persons surveyed are indicated here.

years (AKOPNIKPÈ *et al*., 2010; ALLÉ *et al.*, 2013**;** MERTZ *et al*., 2012; NIELSEN et REENBERG, 2010; OUÉDRAOGO *et al*., 2010; TAMBO and ABDOULAYE, 2013; TSCHAKERT, 2007; WEST *et al*., 2008).

One of the main explanations for the difference between perceptions and observations is often the unsuitable spatial scales used for comparisons. Meteorological observations are often performed at a regional scale while the population always perceives climate at a local scale (HARTTER *et al*., 2012; WEST *et al*., 2008). However, precipitation can be subjected to strong local variations caused in particular by convection phenomena. On the other hand, perceptions are probably fashioned by exceptional climatic events and by the intensity of their impacts. Changes can thus be perceived in a much stronger manner—and even contrary to the overall trends actually observed (HARTTER *et al*., 2012; ORLOVE *et al*., 2010). Farmers' expectations with regard to climate can also influence their perceptions of climatic changes. MEZE-HAUSKEN (2004) suggests that the increasing rainwater requirement of Ethiopian farmers encourages them to interpret recent changes as a rainfall deficit, while observations show that precipitations are stable.

In Benin and Senegal, where the perception of temperatures was surveyed, it is seen that the populations questioned were less sensitive to the rise in nocturnal temperatures, even though this was shown in observations. An increase in temperatures in recent years was found by 69.6% of the persons surveyed in Senegal in comparison with only 60.6% in Benin. It was even observed that 16 and 20% persons surveyed in Senegal and Benin respectively perceived a fall in nocturnal temperatures. Similar results were obtained for the perception of day temperatures. This percentage of temperatures in apparent contradiction with observation can be explained among other things by the fact that temperature increases slowly and steadily, making warming difficult to perceive. Furthermore, temperature is not perceived as a vulnerability factor by populations who tend more to mention changes in rainfall (drought, late start and shortening of the rainy season, intense rainfall events) as causing more damages to crops and therefore having an impact on the daily life of populations.

During these surveys in Benin and Senegal, the persons questioned frequently mentioned strong winds that endangered crops. More than 80% had observed an increase in the frequency of high winds causing damage to crops. This is considered in both Niakhar and Djougou as the second most devastating environmental phenomenon for crops—after drought. However, analysis of average winds at the two locations does not seem to corroborate an increase in winds, even if the wind data at both of these stations suffer from many problems of quality (breaks in homogeneity, aberrant figures, missing figures) and are only daily averages and not maximum instantaneous readings. However, it should be noted that this perception of increased wind by rural populations is also reported by several authors in West Africa (OZER *et al.*, 2013; ALLÉ *et al.*, 2013**;** OUÉDRAOGO *et al.*, 2010) while all wind speed measurements tend to indicate the opposite. ALLÉ *et al.* (2013) suggest that the difference between perceptions and observations of wind speeds in southern Benin can be explained by a serious degradation of plant cover as a result of landholding pressure and the over-exploitation of natural resources, leading to changes in local wind patterns.

Does everybody perceive the climate in the same way?

Unlike town-dwellers in the North and the South who are generally disconnected from their natural environment, the people who work directly on the land using natural resources—especially in traditional societies—are still strongly linked to nature, because their means of subsistence depend on it (WOLF et MOSER, 2011). It can therefore be expected that the experience and knowledge of the environment and climate of rural people—and mainly crop and livestock farmers—are markedly different to those of town-dwellers. Likewise, perceptions of climate—when based on personal experience—are probably constructed using a certain number of factors such as access to meteorological information, the level of education, social networks, economic level, occupation, demographic variables (age and sex) and duration of residence.

Survey EMCV/A-2011 is an ideal framework for analysing these differences as it concerns an extremely varied population of 4,045 households distributed throughout Niger. It thus makes it possible to compare perceptions of climate collected in urban and rural areas, in semi-arid to arid regions and in sedentary and/or nomadic environments. χ^2 tests applied to perception data reveal significant differences according to the level of education, sex, nomadic or sedentary mode of life, rural or urban habitat, occupation and the rainfall at the place of residence. Nomads, men, rural people and uneducated persons living from activities that are strongly dependant on climate (crop farmers, livestock farmers) and in the driest zones have sharper perception of the recent worsening of rainfall in Niger. It can be explained easily by the fact that these population categories are dependent and vulnerable with regard to climatic variability and hence have a live memory of recent pluviometric events. In contrast, the age of the respondent does not seem to have affected replies. This can be explained by the fact that the questionnaire concerned the previous five years and not an earlier period.

Figure 7 illustrates this difference in perception of pluviometric variability in Niger by groups whose income is directly dependent on the climate (crop and livestock farmers) and those whose incomes are independent of the climate (civil servants, craftsmen, traders, self-employed workers, unemployed). It shows that climate-dependent populations have a much better perception of variations in the onset of the rains. Indeed, the high positive (negative) Pearson residuals for late (early) starts imply that the number of respondents mentioning a late start of the rains is very significantly higher (lower) than that expected by a random response. Perception is also good when persons are questioned about the start of the monsoon during the last five years or the start of the monsoon in 2011, which took place several months before the survey. This matching of perceptions and pluviometric observations contrasts strongly with those of populations whose incomes are independent of the climate. The replies in these surveys even sometimes mention a later start of the rains in contrast with observations that show that it is earlier.

Unlike Niger, the Senegalese survey was focused on a population that was fairly homogeneous as regards its characteristics and activities. All the persons questioned were crop/livestock farmers living in a rural area and all using the same millet and groundnut based farming system. However, as for the results for Niger, differences in perception can be seen between persons, regardless of their work as farmers and their place of residence.

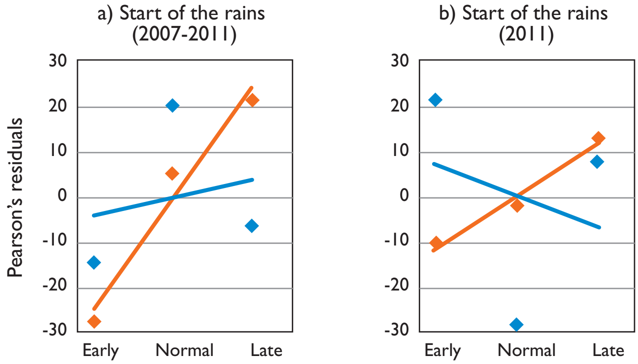

Figure 7.
The proportion of households that perceive a later start to the rains during the last five years (left) and during the last rainy season (2011). The ordinates represent Pearson's residual with, in red, the answers of persons questioned whose incomes depend directly on the climate and, in blue, those whose incomes do not depend on the climate.

A logistic model (Table 2) is used to see first of all that the perception by Senegalese farmers of climate and changes in climate matches scientific observations best when their occupations are mainly or solely in farming. Thus farmers with at least one non-agricultural occupation have less likelihood than the others of achieving good perception of recent climate change (OR = 0.77; p = 0.045).

However, in contrast with our hypothesis, having made several seasonal migrations during the last 10 years does not affect farmers' perception of the climate. This can be explained by the fact that seasonal migrants who possess land are always present in their village at the start of the farming season (before the first useful rain).

The other factor related to good perception of recent climatic evolution is regular listening to the radio weather forecasts. Farmers who do this are more likely to make an accurate detection of climate changes in conformity with observations by climatologists (OR = 1.61; p = 0.001). This of course shows the importance of access to

Table 2.
Analysis of the factors related to very good perception of recent (less than 10 years) climate changes by farmers in the Sine in Senegal.
Logistic regression for 1,017 farms (questionnaire survey, ESCAPE – 2013/2014).

	Complet model	
Number of observations (total ; yes ; no)	(1 017 ; 460 ; 557)	
Good perception of the climate	Odds Ratio	P>z
The person is a woman (or a man)	1.12	0.509
The person has never been to school (has been to school)	1.15	0.355
Age	0.99	0.690
Number of seasonal migrations in the las 10 years		
1	0.96	0.828
2 or 3 r	1.03	0.895
3 or more	0.61	0.302
Usually has a paid non-agricultural occupation (or not)	0.77	0.045
Caste		
Noble (or peasant)	0.87	0.403
Artisans ou griots (or peasant)	1.98	0.011
Member of a farming association (not a membern)	1.14	0.385
Use meteorologocal information in his/her work (does not)	1.61	0.001
Religion		
Mouride muslim (or Tidian muslim)	0.73	0.051
Christian (or Tidian muslim)	1.24	0.346
Poor(or not)	0.84	0.198
Constant	0.90	0.787
ROC curve	0.61	
Hosmer-Lemeshow test (prob. value)	0.59	

meteorological information for better perception of the climate. However, it also suggests that the perception and interpretation of the climate is a cumulative set of knowledge, beliefs and observations that evolves by adapting to new experience (BERKES *et al*., 2000). The integration of scientific and lay knowledge shows that the latter category can form a framework of reference within which farmers interpret and adopt scientific information such as weather forecasts.

The quality of perception of the climate also has cultural and social aspects. The craftsmen and griot castes thus have better overall perception of the recent evolution of the climate than the Serer of the farming caste (OR = 1.98; p = 0.011). In our study, this group is represented mainly by griots, who conserve the collective and family memory. This means that they might be more sensitive to the changes that occur with the passage of time, and especially changes in climate. Conversely, it is observed that muslims who belong to the Miuride brotherhood perceive recent changes in climate less well (OR = 0.73; p = 0.051). The Mouride organisation features among other things economic and religious networks superimposed on a both national and transnational territory whose focus is the holy town of Touba (COPANS, 1980; BAVA, 2005). Mouridism thus involves great mobility among its members who often benefit, thanks to trade, from the difference in wealth between places. Even when they are farmers, Mourides thus have more inclination to travel and trade—both of which tend to cause a degree of disconnection with their natural and climatic origins. It is noted that the residents of the villages in the north of the observation zone where the Mouride influence is stronger (it is at the edge of the Diourbel region where Touba is sited) and extra-agricultural activities are more frequent have significantly poorer perception of climate than those of the villages in the south of the zone.

Overall, it is seen that individual perceptions of the climate are modelled by experience and beliefs and also according to the scientific knowledge that persons integrate. Furthermore, what is doubtless most important is the link between persons and nature, in particular through their occupations and lifestyle. This determines the accuracy of their perception of climate in comparison with scientific observations.

Conclusion

Good perception of the climate by African farmers is certainly an important issue in adaptation to climate change insofar as they are accustomed to managing their fields according to their perceptions and beliefs in terms of nature and climate. Accurate perception of the climate is hence necessary for assessing climatic risk and having the possibility of managing it well. This perception clearly does not automatically induce a rational action with regard to climate. Other risks or competing stresses may determine farmers' adaptation strategies (TSCHAKERT, 2007). However it is undoubtedly a necessary condition and one that meteorological information can help to reinforce.

In spite of natural climate variability and biases associated with memory, we have seen that the farmers in semi-arid zones in Africa have fairly clear and accurate awareness of recent climatic changes. However, it should be considered that this awareness is all the more clear-cut as climate change is taking place over a fairly short period of time and has considerable amplitude, as in central Senegal and certain parts of Niger. In contrast, it might be imagined that a more gradual change—such as a gradual increase in temperature for example—would be more difficult to detect and hence more difficult to face. The perception of climate change also depends on its impacts (positive or negative) on the way of life and standard of living of the persons who feel them. The violence of recent rainfall in Senegal caused phenomena (flooded houses, uprooted trees, etc.) that have probably marked the minds of farmers. Likewise, increased rainfall and the late end of the rainy season have changed the farming system, with the reintroduction of long cycle millet (see Chapter 18), contributing here again to better memorisation of changes in rainfall. In contrast, farmers pay less attention to climate warming, which has less impact on their work for the moment, but which for climatologists is nonetheless the most definite and the strongest signal.

In the light of all these remarks, we can affirm that perception by farmers is currently as much that of the impact as of the climate phenomenon that causes it, and that it's more the perception of uncertainty that that of the risk. We should therefore not be surprised to observe that farmers adapt to the change once it has happened, that is to say in reaction and not anticipation. Learning by observation alone is generally not enough to anticipate adaptation. For this, the signs of nature and the sky must be interpreted so that they might express a danger against which the populations will seek to protect themselves. These interpretations are in the course of construction today by both local beliefs and by the scientific knowledge to which African farmers have access.

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Chapter 5

When nature talks to us
Comparative analysis of representations of climatic and environmental changes

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Introduction

Farming societies everywhere are always concerned by meteorological developments in both the short term (special meteorological events) and on a more long-term scale (climate trends). There is talk in all societies aimed both at describing the meteorological changes perceived as the seasons go by and at what might be the reasons for the perceived, observed changes. Rural societies do not perceive or interpret the present climate changes in the same terms as those of technical/scientific approaches (BASSET and CRUMMEY, 2003; KORBÉOGO, 2013). Collecting popular perceptions of meteorological changes makes it possible to both compare 'popular' and 'academic' knowledge and obtain information about the specific practices that may result from these representations. Indeed, farming practices are often determined directly by the perceptions that farmers may have of the supposed meteorological pattern as the season in question proceeds. It is thus essential to collect stakeholders' accounts in order to understand their farming practices, their choices with regard to sowing date or technique, the moments chosen for harvesting and the conservation techniques used for heads or grain. Like any attempt to improve agricultural production, enhancing the safeguarding of harvests in spite of the meteorological changes effecting the wet seasons requires close discussion with farmers and intrinsic understanding of their reasons for using a certain technical option rather than another.

Perceiving means deciding. Perceiving means choosing from the mass of information available that which is relevant for the action planned. It is not just combining and weighting but also and above all choosing—choosing between rival forms, taking decisions in sensorial conflicts. Perception means decision and so does memory, with equal importance. Many sometimes contradictory perceptions coexist in the same society and may compete with each other. The data collected are from qualitative type anthropological and geographic surveys conducted in five different regions of West Africa: the Niakhar zone in Senegal located in the heart of Serer country in the groundnut area in central Senegal, the Djougou region in north-west Benin and finally the Bonkoukou zone in Niger, 100 km east of Niamey. Secondarily, interviews were also held near Podor in in the Senegal River region and in the Wankama region (Dantiandou) in Niger. The data collected indicate both the diversity and richness of perceptions of climatic and environmental changes, the plurality of the representations that explain these changes and the multiplicity of the practices used to address them. Beyond this diversity, bodies of perceptions and representations are common to the various zones considered with regard to both rainfall and the natural environment and its changes. The stakeholders encountered at the three main locations perceived three phenomena clearly: changes in features that characterise climate such as rainfall, temperature and winds. New features are emerging such as dust and grass species and known features such as ponds, fauna and shrub and herbaceous species are disappearing. Natural cycles and rhythms have always been upset periodically by events considered by witnesses as being exceptional. It is clear that this ‘exceptional’ feature must be examined. The discussion proposed here is hinged in what can be perceived by stakeholders themselves—such as continuity, change or true breaks.

The issue of translation, a challenge for anthropology?

Any anthropological survey requires considerable translation work. The questions that preoccupy a researcher are formulated as questions that can be submitted to the stakeholders encountered. Anthropology requires considerable semantic translation (Olivier de Sardan, 2008). Likewise, qualitative interviews conducted by a geographer and centred on questions of the perception and representations of environmental changes require the same effort as for semantic translation. The question of popular meaning and academic meaning is raised (Olivier de Sardan, 2001)

The notion of ‘environment’ is a recent elaboration in and by western societies (Acot, 1988; Moscovici, 1977; Abélès *et al.*, 2000; Descola, 2000). The notion of climate is too often related to meteorological variations in common parlance whereas researchers examine very long periods (centuries and at least decades). Thus how can the notions of ‘climate’ and ‘environment’ be translated? How is it possible not to give bias to the statements and reports of the people with whom we have discussions and make the most accurate possible description of the changes that they perceive and the associated representations? Attention has always been paid to meteorological phenomena and climatic variations by all social groups and especially those who draw their resources from the land, from animal husbandry and from gathering (FAIRHEAD and LEACH, 1994, 1996; KORBÉOGO, 2013). Thus rainfall, wind and temperature are factors around which the questions asked acquire meaning. There are vernacular terms to indicate these features that are more neutral and concrete than climatic and environmental changes'. For rural people, these terms better give a true expression of the meteorological events that are signs of climate change in the long term. There are thus no terms to express climate in West African languages. Reference is made on the subject to the nature of the winds, to that of space, with the latter understood as the immediate surroundings including soil and vegetation. Reference is also made to hot and cold, i.e. perceived temperature, and also to the characteristics of rainfall—for example its intensity or variability.

Identical methodology was used at Djougou, Niakhar and Bonkoukou. Most of the data were gathered during three collective surveys of the 'Ecris'[1] type (BIERSCHENK and OLIVIER DE SARDAN, 1994), part of which concerned representations of meteorological, environmental and climatic changes. The surveys were conducted in November 2011 in Bonkoukou (Niger), in April 2012 in Niakhar (Senegal) and in November 2012 in Djougou (Benin). Complementary qualitative surveys were performed systematically at each of the locations. They made it possible to focus the data and obtain studies of cases serving as examples. Semi-directive surveys were conducted with Niakhar farmers during the 2013 winter period. Surveys were selected when millet was grown on the largest area of the farm. Semi-directive interviews were also conducted with other resource persons: extension agents (Ancar[2], CADL[3] manager) and heads of villages.

Several ESCAPE programme researchers who are not specialists in social science participated in the Ecris surveys—in particular in Senegal and Benin. The two or three-person teams that conducted the interviews were thus made up of agriculturalists, climatologists, demographers, anthropologists and geographers. The data reporting meetings held every evening were rich in the combined expertise of researchers in social science, agriculturalists and climatologists. The results of the Ecris surveys carried out at the three main locations made it possible to compile the questionnaires for the quantitative surveys drafted by the socio-demographers of the ESCAPE who had themselves participated in the Ecris surveys, and these questionnaires were delivered to Djougou and Niakhar (see. Chapter 4). Here, the results of the qualitative studies are not aimed as much showing the extent of the gap between the population's perceptions of environmental and meteorological changes and the rainfall and temperature records accumulated by researchers in climatology but are aimed more at gauging the knowledge of the population and the representations shared in different ways. Our aim is to report what the populations

1. Ecris : *Enquête collective rapide d'identification de groupes stratégiques* (Rapid collectives survey to identify strategic groups).
2. Ancar : Agence nationale de conseil agricole et rural.
3. CADL : Centre d'appui au développement local.

perceive as continuities and changes or, in contrast, breaks with the experience that they may have of the meteorological and environmental conditions of their living environment.

Continuities: the transmission of knowledge about meteorological forecasting

The rural areas in question feature a body of knowledge and practices that are shared in variable manner according to sociocultural or socioprofessional groups and also according to the age and sex of the persons questioned. This knowledge makes it possible to interpret the nature of the area or the quality of the season and to predict future climatic features in order to adapt to the effects that these may have. It is constructed around signs and symbols, identified in space (with the appearance of disappearance of certain shrub or herbaceous species or their flowering, the cries of certain animals and birds, changes in the direction of winds, the appearance or disappearance of certain stars, etc.) and passed down from generation to generation, enabling farmers to master space and orient themselves in time. This mastery of space means that they can make choices that benefit their everyday work.

The expression of local knowledge is centred on the interpretation of signs observed in the stars, trees and grasses, animals, winds, etc. These signs announce the seasons and their quality. The movement of the stars is the most commonly recurrent feature interpreted by crop farmers while herders tend more to interpret the drying or flowering of trees and herbaceous plants. Amadou Oumarou (2004: 285) thus notes that 'time [for the Peuls of the Dallol Bosso (Niger)] displays a repetition of circular environmental phenomena that marks the end of one season and the beginning of another'. The data collected in the areas studied show that:

– the appearance and position of stars determine sowing dates and the quality of future harvests in Niger and the intensity of the rainy season at Djougou in Benin;

– for sedentary farmers, the appearance of different stars marks the beginning or end of sowing and even the end of the rainy season. For example, in Niger the appearance of the *aliije* in Fula (three stars aligned in the east) causes concern if the heads of early millet are not mature. Farmers then know that there will be a maximum of two further rainfall events;

– the desiccation of the foliage of the gao (*Acacia albida* or *Faidherbia albida*, a forage tree: its fruits and leaves are eaten mainly by small ruminants) is a sign that the rainy season is about to begin;

– winds are also indicators of changes of season: the monsoon announces the rainy season, the dropping of monsoon winds announces its end, the Harmattan announces the start of the cold, dry season and whirlwinds at the end of the Harmattan announce heat.

Likewise, certain behaviour of animals and birds announces the winter season: the appearance of a bird called the *'walia'* (in the Djerma and Haussa languages) and '*waliaje*' (in Fula) and the croaking of toads herald the arrival of the monsoon within the following two weeks. At Djougou, the sound of a bird considered to be very intelligent announces the start of the rains. Farmers say that it speaks several languages (in Yom it is *kpas -noo a* 'the one that announces the rainy season'). The Peuls use the Yom name. The bird sings once in February, twice in March and then many times towards the end of March, showing that the rainy season should start 20 days later.

The behaviour of birds and animals sometimes enables stakeholders to measure changes. An old man in Djougou thus said that before the period between the increase in the song of this bird and the arrival of the rains lasted no longer than 10 days but that today the bird may sing a number of times and the rain is still slow in coming. He now mentions a gap of at least 20 days. The bird thus indicates that the rains start later.

Stakeholders also mention *disturbances in the direction of winds* and the *temperature of these winds* (wind is felt to be warm when it should be cold and vice versa) as a major change, showing more serious changes whose causes they do not know and that they have not experienced in the past.

Changes observed in climate features: rain, temperature and wind

Farmers' perceptions of climatic and environmental changes are centred on as many representations that they make of meteorological features consisting of precipitation, temperature and wind and of the changes affecting their natural environment: ponds, vegetation, watercourses, etc. This perception must therefore be analysed starting with the characteristic features of each of these components. In emic perception (Olivier de Sardan, 1998), the climate of the study area refers to rain, wind and temperature. The popular perceptions described here that are related to these features show the homogeneity of the changes observed in Niger, Benin and Senegal.

Disturbances of rainy seasons

The disturbances of rainy seasons take the form of the lateness of the first rain or of the effective settling in of the rainy season, irregular rainfall poorly distributed in both time and space and an early end of the rains. Several of our surveys show the interdependence of these various factors of disturbance of the normal progress of rainy seasons. While in Niger the first rains were recorded in the 7th month of the farming year and lasted for four to five months, in recent years the first rains have generally been between the 8th and 9th months, resulting in shortening of the duration of the rainy season to a maximum of three or four months in this case. Irregularity and poor spatio-temporal distribution of rains have thus become recurrent and are the main signs of the disturbance to rainy seasons observed for several decades.

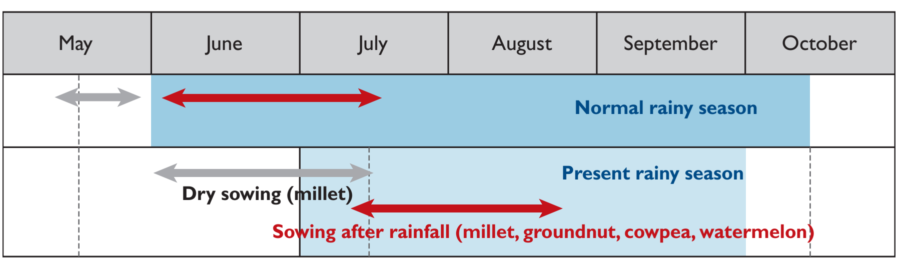
Farmers see the lateness of the first rains as the main cause of poor crops. We were told at the three locations that 'The later we sow, the more risk there is of the rains stopping early'. Descriptions include changes at the beginning and end of the rainy season and patches of drought. The latter are more numerous and more marked today than before the two major droughts in the Sahel in 1973 and 1984. This increased intensity and duration of drought patches causes problems for plant growth. The villagers stress that the rains no longer come 'at the right moment' for crops: precipitations start before sowing and return after what should have been the date of the sowing. Rainfall has thus become irregular: 'We don't understand any more!'. For example, the increase in rainfall and the rise in temperature in the Senegal River valley result in increased pest risk, thus making market garden crops vulnerable.

In Serer country, farmers in the Niakhar region observe the shortening of the rainy season. Today, the rainy season lasts for hardly three months instead of five months as in the past.

The rainy reasons have featured a late start and early end of precipitation during the last three decades. Heavy rainfall for very short periods generally alternate with drought periods lasting for 5 to 20 days according to the persons surveyed. The patches of drought observed between rainfall days hinder crop growth. They are observed within the same village terroir. Indeed, the areas covered by rainfall have decreased in all the zones studied. It can happen that in the same village area part receives rainfall while the rest does not have a single drop! Farmers have responded to this uncertainty in rainfall. The period 1961-1990 was marked by major changes in farming practices, a drier climate and the gradual abandoning of 110-120 day long cycle millet (Sanio), the spread of dry sowing of millet in the groundnut region and the cultivation of bottom land. These features show the links between rainfall and the changing of farming systems.

Today, farmers combine long cycle and short cycle varieties to face these forms of rainfall risk. The example of the combining of Souna millet and Sanio millet in alternate seed holes in the same field on farms in the Niakhar region illustrates this.

Table 1.
Changes in periods of rain and sowing periods, expressions of climate change.



Thanks to the increase in rainfall (2007-2014), the remarkable reappearance of Sanio in land in the Niakhar region since 2009 shows the reversibility of farming practices that are continuously adjusted to the pattern of rainfall. The water requirements of Sanio are estimated to be around 544-598 mm (DANCETTE, 1983). It is reminded that this crop, grown in large bush fields from 1965 to 1969, covered an average of 33% of the cultivated area of the village of Sob in the Niakhar region (LERICOLLAIS, 1972). During the 1986 farming season, a little Sanio was noted at Sob, Ngayokhème and Kalome (FAYE *et al*., 1987).

Changes of temperature

Changes of temperature during the dry and cold seasons are also perceived by farmers as one the major factors that indicate climatic changes. In the past, dry seasons were sunnier and displayed much higher temperatures, giving a good rainy season as precipitation was regular and abundant for the four months of the winter season.

> 'At the height of the day during dry seasons, rays of sunlight were so hot we often had the impression of burning. When the sun was high in the sky, it was not possible to walk on the ground without shoes and the birds took refuges in the granaries and houses. And this intense heat was the sign of heavy rainfall and good harvests' (interview of a farmer in the village of Wankama, September 2012).

The cold seasons also feature particularly cold peaks. In certain periods, especially in the cold season, old people had to keep warm with a fire from the morning to midday. These intensely cold moments are called '*dottidjo bon dan barnu*', an expression in the Djerma language meaning that the old people go so close to the fire that they give the impression of putting their heads in it.

During an interview, the head of Podor meteorological station mentioned the very marked increase in temperatures in the river basin. The rise accentuates evaporation and causes water stress in crops, especially during the warm counter-season (from March to June). Farmers must perform regular watering and thus cover the extra cost of the irrigation facilities used. This statement by the person we had a discussion with at Podor clearly illustrates the rise in temperatures in the zone:

> 'It has been so hot that the insolation measurement apparatus was burned and damaged. This is shown by gaps in the record sheets. However, the data must be given by telephone at every hour of the day to the meteorological agency in Dakar' (talk with the head of Podor station, July 2013).

Mentions of high temperatures—especially at the beginning of the rainy season—were collected at all the survey locations. Indeed, the persons we talked to have acute perception of temperature variability in the same season.

Changes in wind characteristics

Wind characteristics concern wind direction, force and whether wind is reddish or not. According to the persons we talked to, wind direction in the past depended on the season. The wind blew from a precise direction in each season. However, this principle has been considerably disturbed today. For several years the wind generally blows from any direction. The precision in wind direction that indicated each season no longer exists. A new type of wind is observed, which is generally reddish, dry and hot, violent, sudden and fairly frequent. The high frequency of these winds in an environment subjected to strong deforestation caused by abusive felling causes erosion, the unusual formation of *koris*, runoff and flooding. All these factors participate in the impoverishment of cultivated areas. The winds also transport reddish dusts that cause illnesses of all kinds among the population, especially in the cold season.

Breaks: between the disappearance of 'known phenomena' …

Several features of the immediate environment (shrub species, ponds, etc.) and known, usual meteorological signs are now little visible or not at all in farmers' areas. Various shrub and herbaceous species have been reported as disappeared or disappearing in all the study locations. At the locations in Niger this mainly concerns trees such as *Ziziphus mauritania* (*darey), Balanites aegyptiaca* (*garbey), Acacia polyacantha* spp. (*dan), Grewia bicolor (kélli), Acacia macrostachya (tchidi), Adansonia digitata* L. (Bombacaceae) *(koo nya*), *Combretum nigricans* (*déli-nya*), and edible herbs or species with medicinal uses (treatment of fever, stomach ache and diarrhoea): the hanza, *Gynandropsis gynandra (fubey), Leptadenia hastata (hanamm), Cassia occidentalis, Chrozophora brocchiana*, etc.

At Niakhar, many persons questioned explained that the landscape used to be 'darker' as the trees had much more foliage.

> 'At that time, there weren't the big surveys that people do now. To go to Niakhar, you had to walk for 5 kilometres and it was forest between Sob and Niakhar. There were robbers; if they killed you they took you baggage and went off and you lost the herds too, they killed the herders and took the oxen. We carried the harvests through the forest, we had nowhere to put them, we carried them on our heads. We carried groundnuts on our heads, and millet and kindling too. If you couldn't put it on your head you rolled it along the ground. I experienced all that … ' (interview with a 90-year-old man in the village of Sob in the Niakhar region, July 2014).

The reference made by this person concerning the demographic monitoring surveys performed at the Niakhar location since 1962 makes it possible to date the decrease in numbers of trees and the thinning of forest to more than 70 years ago (before 1945). People in the Niakhar region also mention the disappearance of market gardens since the 1970s in Serer country. Soil erosion and intense degradation by salinisation of groundwater are visible.

With regard to water resources, the disappearance, shrinking and/or early drying out of ponds at the three locations were noted by the populations. Thus accounts in

Djougou recount the drying of small watercourses (Doubiera, Biyigui, Adjeta-Behma), and then of medium-sized ones (such as Mara) and finally the shrinking of the largest watercourses (Bakou, Massy, Wewe and Sew). Another feature displaying disappearances is the fauna in village areas. The interviews thus report the disappearance of big cats and scarcer large and small game in the Djougou region. Likewise, the persons questioned at Bonkoukou said that deer, guinea fowl, hares, bustards and jackals had disappeared from the area.

… and the appearance of 'new phenomena'

In Niger, the appearance of reddish dust previously little known by the population led to questions and concern. The appearance of unknown plats or the proliferation of recent plants such as purple witchweed is mentioned at the three locations. This plant is only grazed by livestock in extreme cases and farmers know it makes land unsuitable for cultivation. The long dry periods identified by farmers enhance the rapid growth of witchweed (*Striga hermonthica* or *ndoxum* in Serer) and the appearance of insect pests on plants. The spread of witchweed is a sign of the impoverishment of cultivated land. Serer farmers consider it to be very harmful for millet as it prevents plant growth. As a result, its spread heralds a decrease in millet yields in the zone. The return of wetter conditions perceived by the population is leading to the reappearance of plant species that had disappeared. This is the case of the '*pattuki*' and the '*selew-lew*' in the alluvial valley of the Senegal River. '*Pattuki*' (in Pulaar) is *Acacia polyacantha*, a medicinal plant used as an antiseptic and for general tiredness, aches and pains in the side. '*Selew-lew*' (in Pulaar) is *Leptadenia pyrotechnica,* a multi-purpose medicinal plant (treatment of eyes, dermatitis, use as a diuretic and for constipation and colic). Its branches are woven to make ceilings in dwellings and sheds and also to make fencing for housing and enclosures for livestock in the alluvial valley of the Senegal River.

The repeated floods during the last 10 years throughout West Africa (Ouagadougou, 1 September 2008, etc.) have been mentioned in one of the zones covered—the River Senegal valley—as a new and intense phenomenon. Thus in an interview in January 2013, the head of the village of Sinthiou Diambo told us that during the 2012 rainy season 80% of the land equipped for irrigated farming was flooded because of the heavy rains. However, the farmers—fervent believers—facing the climate risk simply said 'God gives us rain when he wants and where he wants'. The 2012 floods that affected a large number of the irrigation systems of the Podor SAED[4] delegation was the result of the heavy rains that year, after that of 1999 that had caused an exodus of a whole village, Donaye, located in the alluvial valley.

4. SAED : Société d'aménagement et d'exploitation des terres du delta et de la vallée du Sénégal.

Table 2.
The damage caused to irrigation systems by the heavy rains during the 2012 rainy season.

	Affected area	**Area flooded**	**Sown area flooded**
Figures (ha)	1 329	984	942
Figures (%)	100	74	70

Source: SAED, Direction des aménagements et de la gestion de l'eau (DAGE) Podor, 2013.

Here, rainwater flooded 1329 hectares of land, making it unavailable for crops. The damage consists of a loss of investment in 942 hectares under rice, affecting 3,588 farmers. In the Guédé rural community (after 22 years of operation of the irrigation system), the smallest area under rice was recorded in 2004, with 537.99 ha. This goes a long way towards explaining the damage caused by the flooding of perimeters equipped for irrigated farming.

The causality of changes in the climate and the environment

Interpretations of the causes of climatic and environmental changes are centred on two major trends: anthropic causes and those related to sociocultural representations.

Anthropic causes

Acts by humans form one of the main causes given for the changes perceived. First and foremost comes the perception by all persons that the population has increased during the last 20 years and the acceleration of the use of natural resources results directly from this. Stakeholders also explain this increase in the use of resources by an increase in commercial operations—generalised in the Djougo region (Langewiesche, 2004, 2006). Thus charcoal-making in the Djougou and Bonkoukou regions meets the financial requirements of women and results in faster tree felling. The doum palm, *Hyphaene thebaica* (whose leaves are used for making mats, ropes, winnowing baskets, hats, etc.) is also sold increasingly. At the three locations, tree felling, the reduction of fallows and the disappearance of animal species are perceived as a direct consequence of human activity—through both deforestation and agricultural colonisation. Pressure on cultivable land goes back a long time in the Niakhar region (Lericollais, 1999) and is mentioned systematically by our respondents. At Wankama for example, deforestation following the abusive felling of timber for sale is the main indicator of environmental changes.

This decrease in shrub species results in the unusual formation of ponds which, in the opinion of local farmers, is the cause of strong winds that result in the decrease or poor distribution of quantities of rain; the erosion of crop fields and the burying of young seedlings mean that farmers have to sow several times in the same year. Indeed, although winds could be strong at times in the past they were never as violent as they are today.

The increase in the numbers of transhumant cattle is reported to have hardened the ground by trampling. The land is first of all more difficult to till and, second, rainfall blocks the ground and can no longer infiltrate. Thus the herds in the Djougou region that belong to Peul cattle farmers are accused of damaging areas around ponds and contributing to silting. In Niger, serious and sometimes violent disputes between herders and rice growers are caused by the drying of water points—blamed on trampling by cattle. The practices of transhumant herders are stigmatised in the Djougou region.

Causes associated with sociocultural representations

From the sociocultural viewpoint, the main cause of climatic and environmental changes mentioned by respondents is endogenous and related to the abandoning of certain sociocultural values constructed in particular around rites and sacrifices.

Indeed, the gradual abandoning of certain practices involved in autochthonous religions and also those of Muslim marabouts is mentioned in conversations about the causes of changes. In both cases beliefs associate certain rites (sacrifices or prayers) and the depth and quality of annual precipitations recorded at a location.

Interpretation by marabouts, Islamic scholars

In the Bonkoukou and Wankama regions of Niger, Muslim marabouts make a link between natural events and the succession of prophets. This form of interpretation enabled them to predict the characteristics of each rainy season and choose the corresponding rituals and sacrifices Thus at each rainy season the marabouts asked the people to sacrifice a chicken, a goat, a sheep or a cow. The animal to be sacrificed was either given by the head of the village or purchased using sums given by the population. It is stressed that these sacrifices were performed outside the village and the meat had to be eaten on the spot, without which the sacrifice would have no effect. These forms of sacrifice are becoming more rare in villages, although some survivals can still be seen.

Rites practiced by zimmas, the holders of local animist beliefs

In these regions of Niger, *zimmas* (a term in Djerma indicating holders of magico-religious knowledge) performed their '*foleys fooris*' or '*Doboussosso*', ceremonies of possession dances. To organise the ceremonies, people make contributions and bring cereals to the *zimmas*. The practice of the *zimmas* is organised in the seventh month of the year and is aimed at predicting the amount of rainfall in the year and the spatial distribution of rain in the village area. The predictions enable the population to be warned of risks of drought or flooding.

For example, in Bonkoukou, the *zimmas* used a fairly simple but strongly symbolic procedure that runs as follows in this description by a respondent:

> 'Two lines at right angles to each other were scraped in the ground and a calabash of special water was poured out at their point of intersection. And, naturally, this water ran along the lines marked in four directions representing the four cardinal points. Spatial distribution of rains is defined by the amount of water that may run on each side of the pattern traced. If for example the eastern segment receives more water than the others, this would mean that annual rainfall will be much greater to the east of the village and its surrounding area' (interview performed in 17 July 2012 with one of the persons involved in the organisation and holding of the *Doboussosso*).

This practice also consisted of preventing attacks by insects that could destroy the crops. And apart from the money and cereals used for the organisation and holding of the '*foleys fooris'* or '*Doboussosso'*, the *zimmas* had the right to further payment in kind. Thus at the end of each harvest, each household had to give a bundle of millet to the chief *zimma*. The latter used this as he wished, generally distributing it to the 'needy' (usually old or indigent people).

But all these practices have now been abandoned for several years, in particular because of the advent of new Islamic practices. This new religious trend interprets these practices as a form of association of beliefs that it terms a 'great sin' as they are related to animist practices. And may respondents consider that all the difficulties encountered today can be blamed on the abandoning of these practices considered to be traditional. Indeed, all the threats prevented by these practices are those involved today in the situation of climatic and environmental changes that make seasons and crops unpredictable and precarious.

Various rites that are now abandoned were mentioned during the surveys conducted in Niger. Each year, propitiatory rites were performed to ensure that the harvest would be good. Thus, before sowing a grain crop, a white chicken was sacrificed to ask for a good farming season. A rite that can be qualified as circumstantial, that is to say that is only performed in certain circumstances—in this case when there was a long period with no rain during the rainy season—was performed. During this rite, women and children carrying cereal grains of all kinds went around the village, pouring seeds at the feet of the big *gao* (*Acacia albida* or *Faidherbia albida*) and in the cemeteries, thus calling on the souls of the dead and on ancestors. According to the persons interviewed, once the ritual had been performed the rains always came. Collective prayers in the cemeteries or at the pace reserved for the prayers of annual festivals might also take place to make the rains come. All these sacrifices and rituals have now been abandoned.

Avoidance practices were also aimed at not upsetting the cycle of the seasons and their quality. Thus a kind of pact between humans and insects—recounted in the foundation myths—led to not eating *foy youtto (Ceratotheca sesamoides*, whose leaves form the base of a glutinous green sauce much appreciated in Mali). The male elders of the village, considered as wise men, made incantations concerning this very specific type of herb called '*zouloumbou*' or '*foy youtto*'. The pact forbade humans to eat the herb until the harvests. In return, the insects ate the herb and, according to the pact, could not attack crops. However, the pact was broken as soon as someone dared eat the forbidden herb and the insects retaliated by attacking crops.

In the Niakhar region, in Serer country, farmers have used a set of strategies to face the increased scarcity of cultivable land, the impoverishment of soils, the collapse of the groundnut economy and the very marked decrease in rainfall (LERICOLLAIS, 1999). They rely on their experience and on the carefully conserved memory of past farming seasons, which explains to a considerable degree their great flexibility with regard to climatic events (LERICOLLAIS and MILLEVILLE, 1997). In parallel, the use of mystical forces is very important. This is the meaning that should be ascribed to the traditional Khoy ceremony in Serer country. Sacrifices and incantations are performed before the sowing of millet in order to obtain good wintering. In the village of Sob, the ceremony is held before the first rain, on a Wednesday, under a large baobab given the name of the protective genie, *diyamsen*. The date of the first sowing is also set on the completion of the ceremony.

Beyond the question of these abandoned rites, respondents mentioned the breakdown of certain well-known social equilibriums. These failures are expressed around various types of behaviour considered as being potentially destructive for society because of the divine fury that this behaviour generates. Today, four main sets of social behaviour can be noted that are perceived as disturbances.

Failure to respect customary hierarchy in farming activities— and in particular obligations and practices concerning the relation of primogeniture and precedence—is a very important cause of 'ecological disturbances'. It is thus forbidden to hoe before the land chief starts; for good field productivity, fieldwork (hoeing, sowing, ploughing and harvesting) must be launched by a man belonging to a given family in the village, generally the family of the land chiefs that is to say whose whose eldest male handles annual propitiatory rituals and that is considered to be native to the place, that is to say the first to arrive. This elder male must take the first step, alone. Nobody in the village should start to hoe, sow, plough or harvest before this man.

The accentuation of individualism in households is denounced as being a major cause of the upsetting of the cycle of the rains in Niger and in Benin in particular. The decrease or even the disappearance of mutual aid within the same family, between families and in society in general causes disturbances in the progress of the rainy season. According to one of our respondents:

> 'Although in the past you couldn't eat alone, knowing that your own brother, a relation or the neighbour had no food, things are different today. And people are even happy about the difficulties faced by others.' (Bonkoukou, 2012).

Practicing Muslims also consider that what they call '*moral depravation*' and the calling into question of a society built on the power of male elders leads to disturbances of the natural order of things. These disturbances are so great that they affect meteorological changes and are probably one of the causes. The changes in the status of women and children are sometimes seen as the calling into question of Muslim precepts that prefer to encourage the authority of men, heads of households.

Women are accused of ‘not staying at home as God recommends’. Today, women are also accused of ‘being everywhere and having activities of all kinds, going from market to market and exhibiting their bodies’. This is also the subject of sermons by Muslim religious chiefs in Senegal. Young people—both boys and girls—are accused of no longer obeying the orders and advice given by their parents. This very deep-seated calling into question of relations of authority structured by distinctions of age, by sex and by generation is perceived as a major cause of social malfunctioning which, by a ricochet effect, causes malfunctioning of the intensity and regularity of the rains.

Injustice in the management of state affairs is also perceived as a problem that can cause malfunctioning. According to our respondents, the holders of power no longer guarantee justice and equity between citizens. Because of this, the weakest persons endure the injustice of leaders considered to be corrupt. These representations are shared throughout West Africa. Thus on 18 January 2014, heavy rains started in Ouagadougou at 4 am. Old people had never seen such a thing—rain in January in a Sahel country. Interpretations acquired a political tinge and on the same Saturday the political opposition in Burkina Faso held a protest march in opposition of the Blaise Compaore’s government to revise Article 37 of the Constitution that limits the number of times elected persons can renew their seats. While the first interpretations tended to say that Blaise Compaore was so powerful that he could cause very heavy rainfall to prevent the opposition demonstration from taking place, at the end of that day after several thousand people had braved the rain to demonstrate in the street, the popular verdict was clear: this rainfall announced the arrival of a major revolution that would oblige Blaise Compaore to leave power. The event happened 11 months later after the popular insurrection of 30 and 31 October 2014.

All these ‘deviant’ individual and collective behaviours are considered to be such as to provoke divine wrath (in Niger) or that of the ancestors (HÉRITIER-IZARD, 1973) (in Burkina Faso, Serer country in Senegal or at Djougou). Because of the mystical sanctions that they generate, this behaviour causes varied meteorological phenomena: heavy rainfall, floods, red dust wind, the drying of watercourses, etc. Today, animist sacrifices and rituals and those practiced in the name of Islam are considered to be contrary to the new practices of Islam and are gradually being abandoned. But a large number of the persons questioned consider that this abandonment is the cause of climatic changes, the decrease in rainfall, the decrease in crop yields and the degradation of pastoral resources.

In conclusion

Farmers are aware of *long-term trends* (decreased rainfall, drought) and *inter-annual variations of the climate.* The perception of long-term changes is generally expressed by strong landscape markers: the disappearance of plants (tree or herbaceous species), of animals and temporary ponds and the appearance of invasive species. As impoverishment of the soil means that the land is less productive than before in all the zones considered, the population is more aware of the problems associated with the change of the rainy season. The vulnerability of the population is thus two-fold, being both agricultural and climatic and both amplify each other mutually. The question of changes and the ability to face them is raised first of all in terms of soil fertility. The decrease in land productivity combined with the question of rainfall presages the setting up of new strategies to handle this: the recovery of land, increased use of fertiliser (including fertilisers from urban wastes with high toxicity), the development and/or the increase in the growing of companion crops, the introduction of new cultivated varieties or species, the adoption of new agricultural and non-agricultural activities, the evolution of the position of women's activities, an increase in temporary or definitive migration, etc. In parallel, the rise of islamisation and re-islamisation, the degradation of the environment, climatic variations and their corollaries, the expansion of technological resources for meteorological orientation and forecasting are all factors that reduce the dynamism of local knowledge, know-how and practices, even if their presence remains effective in all the areas examined in this research.

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Part II

Impacts of the climate and environmental changes

© I. Mamadou

Flooding in Niamey (Niger, 2012).

Introduction

Laurent KERGOAT

The first part of this book sheds new light on climate variability in West Africa and more particularly in the Sahel. 'The most severe multidecadal drought of the planet' is always the one remembered best, and for very good reasons. This observation still h olds. However, we know that the precipitations of the past decade display a decreasing deficit although this is not the case every year. There are still drought years although they are not as dominant as in 1970-1980. A change in the regime of strongest rainfall is now taking shape. This is accompanied by a spectacular increase in the temperature at 2 metres during the hottest periods of the year—just before and after the rainy season.

This climate variability over relatively long periods has very marked consequences. Indeed, most agricultural production involving both crop and livestock depends on precipitation. In addition, as the populations in practically all Sahelian regions are closely dependent on water resources such as surface water, ponds, reservoirs, rivers and groundwater, the impact that a multidecadal drought has had and still has today can be imagined.

Although imagination and intuition can feed perception and common sense, they are not enough to draw up a precise review of the situation and identify the mechanisms that create the Sahelian environment. An illustration of this is desertification. This is a fundamental concept of the evolution of arid and semi-arid zones that is the subject of an international convention. In recent years, the desertification of the Sahel has generated debate with very different theories, opposing rapid desertification to overall re-greening. The theories are generally supported by very inadequate observations that are sometimes minor and sometimes subjective. 'Re-greening' is a concept derived from the satellite observations available since the 1980s and its interpretation is not immediately clear: is the satellite signal related to Sahel vegetation? To tree density? What causes re-greening? Important answers to these questions are provided in Chapter 6.

Likewise, the recent evolution of water resources in the Sahel is the subject of contradictory theories with a contrast between shortage and increase. Hydrological observations since the 1970s have shown an increase in Sahelian river discharges in Burkina Faso, an increase in the water feeding seasonal ponds in western Niger and infiltration to groundwater. Does the phenomenon cover the whole of the Sahel? Is it caused by changes in land use? Might the situation be reversible during the coming decades? Answers to these questions are provided in Chapters 7 and 9.

Even if climate forecasts are still uncertain (see Chapter 3), reasonable hypotheses can be put forward giving plausible ‘ranges’ for the decades to come when the mechanisms involved have been identified. The physical environment is the point of departure but is not the only feature in these questions of vulnerability. An important link in the assessment of vulnerability in the Sahel is the relation between crop or livestock farming systems and the environment. Chapter 8 contains a detailed comparative study of two ‘terroirs’—one pastoral and the other agropastoral—in which the authors examine the viability of livestock farming in both situations, presenting a set of data and analyses that are rare for this region. Chapter 10 contains a full study of the sensitivity of crop yields to climatic variations. The authors use climate scenarios and show that the most important factors for the Sahel are not necessarily those that might come to mind in a context of rainfed crops. Combined with preceding studies of the changes in temperature in the first part of the book, the results raise questions about agriculture that it is important to address rapidly.

An extremely up-to-date picture of what we know about these questions is shown in the second part of the book. The results and conclusions often differ from what might be imagined outside a circle of experts—and sometimes within such circles. At a time when fact checking and decoding are reaching the media, we hope that this book will be an occasion for broad sharing of knowledge and conclusions. Given the media focus on these questions, their political and social importance and their incorporation in sometimes ideological statements, the responses are critical. I’ll just say here, so as not to anticipate the conclusions of the authors of subsequent chapters, that it is essential to possess rigorous, long-term observations of environmental resources. What these chapters show is that observations—and field observations in particular—on which expertise is based are the main driving force for gaining environmental knowledge in West Africa and elsewhere. They make it possible to drawn up balances, put forward hypotheses and build theories and scenarios.

Chapter 6

Between desertification and regreening of the Sahel

What is really happening?

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Introduction

This chapter is aimed at reviewing the 'desertification' of the Sahel, a source of polemic for several decades, and its 'regreening', a term that appeared with the first satellite observations of plant cover in the 1970s. The debate between the backers of these two diametrically opposed theories is real, and particularly important because this part of the world is known for its high sensitivity to climatic events.

The specific contribution of this work lies in the combined use of remote sensing data at the scale of the Sahel and covering the last 30 years and analysis of long-term field measurements in Mali and Niger. The combination of these different data sources allows better understanding of the evolution of plant cover in the Sahel over the last three decades and checking of the coherence of the satellite observations performed for this purpose. It is thus seen that regreening is undeniable, in particular at the scale of the Sahel, but that opposite trends can also be seen at smaller scales, which means that caution is required in overall diagnosis of the long-term evolution of plant cover.

For many years, the desertification of the arid and semi-arid parts of the world has attracted the attention of scientists and also various international organisations operating for the environment, the media and civil society. Indeed, these regions are very sensitive to climatic variations and in particular the variability of precipitation. The Sahelian climate has experienced a succession of wet and drier periods for tens of thousands of years. In addition, the population has increased very strongly for several decades and this has been accompanied by modifications to the environment that are sometimes very marked (cultivated land, land clearance, deforestation, fires, etc.).

The Sahel region has recently experienced two very serious droughts—in the 1970s and then again in the mid-1980s. These droughts happened during three decades of overall rainfall deficits. The consequences of the drought periods were serious for the population and the environment and contributed to reviving the theory of the desertification of the Sahel. For example, several authors have mentioned a spectacular spread of the Sahara that would soon threaten all African arable land (HUBERT, 1920; LAMPREY, 1975; STEBBING, 1935). However, for lack of more appropriate resources, the studies published were based essentially on local observations at a given moment. Typically, the state of the vegetation was observed at a specific place and at a precise instant to draw up a diagnosis of local 'desertification' or to extrapolate this to plot desertification maps at much larger scales (continental, global) (UNCOD, 1977; UNEP, 1992). But several authors questioned this vision, in particular by examining the seasonal cycle of vegetation and its inter-annual variation (BOUDET, 1979; JONES, 1938) or by calling into question the methods used by the various institutions to spatialise desertification diagnoses (MABBUTT, 1984; VERON *et al.*, 2006).

In this context, the arrival of satellite remote sensing in the 1980s provided an extremely valuable tool, in particular thanks to the vegetation indexes used for the first monitoring of vegetation at the global scale. One of the most commonly used vegetation indexes is the NDVI (Normalized Difference Vegetation Index), calculated from the light reflected in red and near-infrared wavelengths (see Equation 1), since green vegetation absorbs red wavelengths and reflects near-infrared. Numerous studies have shown that the NDVI is linked to the fraction of active photosynthetic radiation absorbed by plants (fPAR) (ASRAR *et al.*, 1985; MYNENI *et al.*, 1995; SELLERS, 1985), and other vegetation variables (all linked with each other) such as plant cover (fCover: the fraction of the ground covered by green vegetation seen vertically from above the cover) and the leaf area index (LAI: leaf area per unit area of ground). Finally, the integral of the NDVI in time is considered to provide a good assessment of vegetation production, in turn defined as the quantity of plant tissues produced during a given period, generally that of the plant growth season (MONTEITH, 1972).

$$NDVI = \frac{\rho_{PIR} - \rho_R}{\rho_{PIR} + \rho_R}$$

Équation 1.
NDVI formula in which ρ_{IR} = reflectance in near infra-red (PIR) and ρ_R = reflectance in red wavelengths (R).

'Regreening', a term dating back to the first satellite analyses

The data collected by AVHRR radiometers installed in NOAA satellites and launched in the early 1980s provided the first opportunity to analyse NDVI at the continental stage and at a time step suitable for monitoring vegetation. The datasets drawn from AVHRR data are still among those most frequently used today for the study of long-terms trends in plant cover as they have unequalled historical depth: several sensors launched one after the other have provided a continuous dataset from 1981 to the present day. The GIMMS dataset in particular has been much used; the first version is available for 1981 to 2006 with spatial resolution of 8 km and bi monthly frequency.

The first analyses of temporal trends of NDVI AVHRR in the Sahel date from the early 1990s as data for 10 years were available. In a study using satellite observations over a long period to examine the hypothesis of the Sahara Desert spreading, TUCKER and NICHOLSON (1999) showed that in fact the "expansion" of the Sahara depends on the inter-annual variability of precipitation. In other words, the hypothesis of an inexorable advance of the Sahara, the supposed sign of the desertification of the Sahel, was invalidated. To go further, the NDVI trends shown are were fact positive and statistically significant trends. These positive trends gave birth to the term 'regreening' of the Sahel, defined simply as an increase of the vegetation index in time. As further years of observations were added to satellite records, this regreening of the Sahel was documented in a number of studies (ANYAMBA and TUCKER, 2005; FENSHOLT *et al*., 2013; HERRMANN *et al*., 2005; TUCKER and NICHOLSON, 1999).

A new version of the GIMMS dataset has appeared recently and is called GIMMS-3g (for 'third generation'). Data are provided for the period running from 1981 to 2011 at a spatial resolution of 1/12° and bi-monthly time frequency. The coherence of this dataset in comparison with other existing NDVI datasets was examined and demonstrated in DARDEL *et al*. (2014 b) and DARDEL (2014). Here, we focus only on temporal trends throughout the entire period for which GIMMS data are available, that is to say from 1981 to 2011 (Fig. 1).

The NDVI GIMMS-3g trends are thus positive in most of the Sahel belt for the whole of the period 1981-2011. Only a few regions like western Niger and central Sudan display statistically significant negative trends. The signature of the regreening of the Sahel is thus clear and confirms recent studies (FENSHOLT *et al*., 2012), this time for the entire period for which AVHRR data are available.

However, as for all data sources, satellite data are subject to a number of limits and to bias, especially in long-term series. It is therefore essential to verify that the signal detected by satellite is truly linked to the evolution of vegetation and not to satellite artefacts. One way of doing this is to compare them to data collected in the field at a spatial scale compatible with satellite measurement. However, such observations are very difficult to make, especially for large areas and for long periods of time, and are thus rare. Within the framework of international projects such as AMMA (*Analyse multidisciplinaire de la mousson africaine* – Multidisciplinary analysis of the African monsoon) and previously under the aegis of the ILRI (International Livestock Research Institute), plant production measurements have been performed in Mali since 1984 (HIERNAUX *et al*., 2009 b; MOUGIN *et al*., 2009) and in Niger since 1994 (HIERNAUX and AYANTUNDE, 2004; HIERNAUX *et al*., 2009 a). In addition,

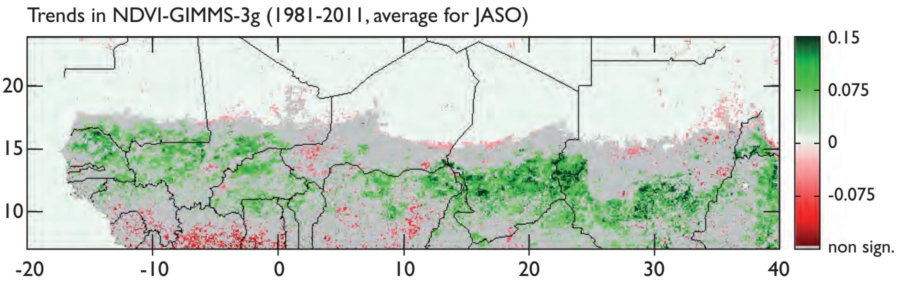

Figure 1.
Temporal trends in NDVI GIMMS3g averaged from July to October for the period 1981 to 2011 in the Sahel belt.
Zones that are not statistically significant (P < 0.05) are greyed.
Source: DARDEL et al. *(2014 b).*

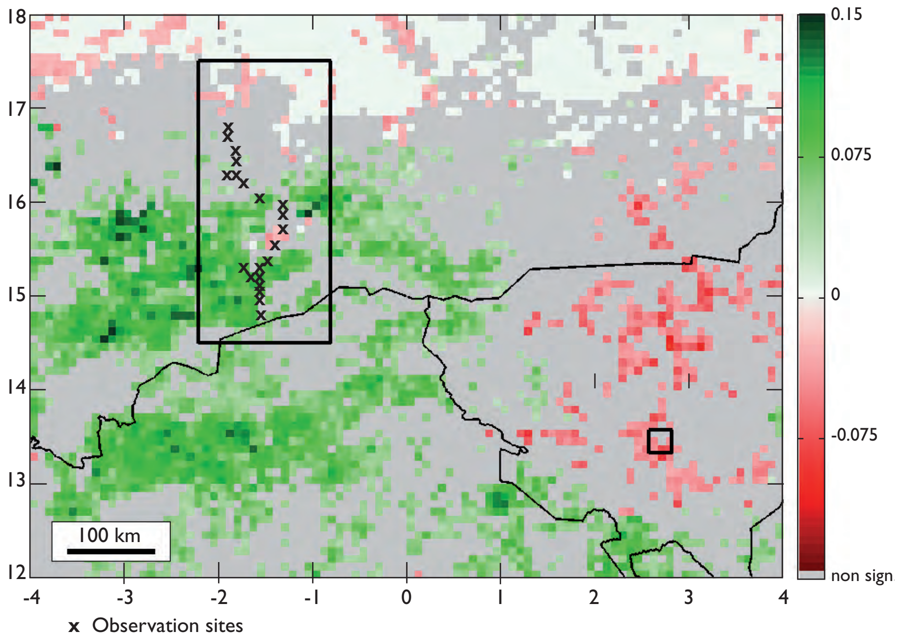

Figure 2.
Temporal trends in NDVI GIMMS3g averaged for the growth season (July to October) from 1981 to 2011: a close-up on the Gourma region in Mali (rectangle on the left) and the Fakara in Niger (square on the right).
The crosses represent pixels at which vegetation sites are present (for the Gourma region only).
Source: DARDEL et al. *(2014 b).*

these two study locations are particularly interesting as they display trends with opposite signs: while the Gourma in Mali is 'regreening', the Fakara in Niger is marked by strong negative trends (Fig. 2). Comparing the trends found by remote sensing with long-term field observations is thus a real test for satellite archives and for their performance in terms of the monitoring of vegetation.

Comparison with *in situ* measurement networks (Mali, Niger)

The Gourma in Mali

The vegetation in the Gourma consists mainly of annual herbaceous plants. The soil is thus mainly bare during the dry season, with the exception of a few perennial plants and scattered shrubs. Herbaceous plants grow if there is sufficient rainfall during the growth period, that is to say from June to October (Fig. 3). The ligneous stratum forms less than 5% of the total area, as do cultivated areas. The land is used mainly for grazing.

Within the framework of a long-term ecological field study, annual plant production is estimated by measuring the aerial mass of the herbaceous stratum, with measurement in kilograms of dry matter per hectare (kg $MS.ha^{-1}$). A destructive method was used for the measurements: the grass was cut, dried and weighed for 1 m × 1 m squares chosen at random along transects 1 kilometre long (HIERNAUX *et al*., 2009 b). These transects sampled the variety of the landscape: the different soil types, vegetation densities, etc. Some 40 sites were thus sampled in this way practically every year from 1984 to 2011. When several measurements were performed at the same site in the same year the maximum mass gives the best estimate of annual production.

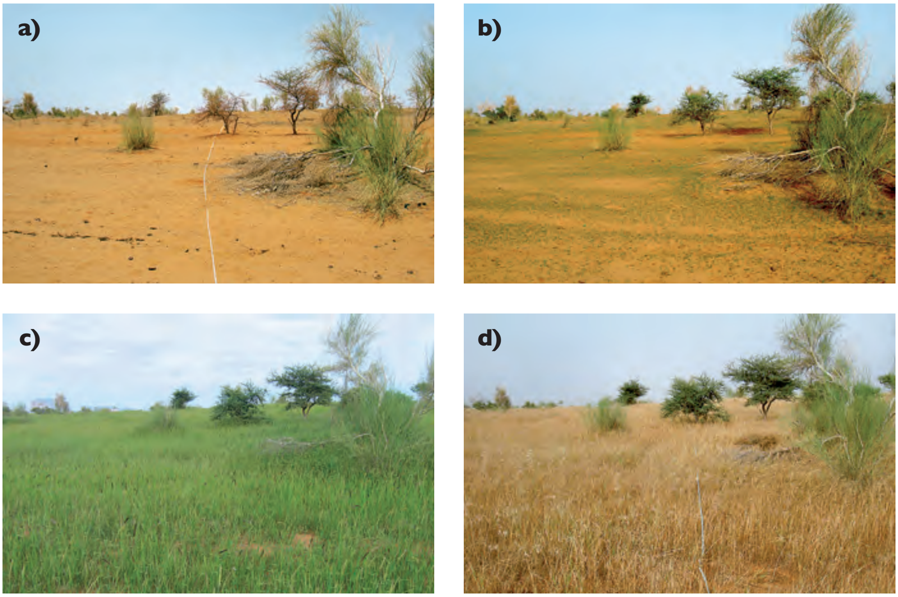

Figure 3.
Annual dynamics of plant cover at Agoufou in Mali in 2005, for a) 8 April, b) 17 June, c) 19 August and d) 28 September.
Source: Photos AMMA-CATCH.

Calculation of the average of the masses measured at the 40 sites sampled from 1984 to 2011 (Fig. 2) gives a time series comparable to the NDVI averaged for the same region (the rectangle shown in the left of Figure 2). The regreening detected using satellite data is therefore confirmed by the field measurements (Fig. 4a). There is good agreement between the two independent datasets ($R^2 = 0.61$, Fig. 4b), proving that NDVI is strongly correlated with the evolution of herbaceous vegetation and that satellites are perfectly suitable for monitoring plant production over long periods of time. Furthermore, these regreening trends demonstrate the resilience of the Sahel ecosystems in the Gourma in Mali in spite of the very severe droughts of the 1970s and 1980s.

These first results show that the regreening of Sahelian vegetation is a proved phenomenon and that the satellite archives are fully relevant for performing long-term monitoring of vegetation, at least in these semi-arid ecosystems.

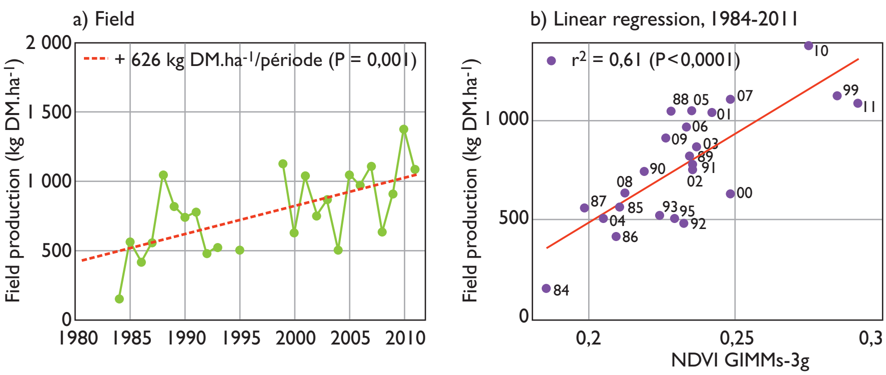

Figure 4.
a) The temporal evolution of field data (mass of the herbaceous stratum) averaged from the sites in the Gourma in Mali, from 1984 to 2011.
b) Correlation between field data and NDVI GIMMS-3g data from 1984 to 2011.
Source: adapted from DARDEL et al. *(2014 b).*

The case of Fakara in Niger

The case of the Fakara is slightly different as this region in south-west Niger has experienced very strong local population growth since the 1950s, combined with a considerable increase in cultivated areas. The proportion of cultivated land surfaces has thus increased from 25% of the total area in 1986 to some 50% in 2010 (HIERNAUX and AYANTUNDE, 2004; HIERNAUX *et al.*, 2009 a). As a result, the areas under fallow have decreased considerably; long fallows have been particularly affected. The land use system is agropastoral with a combination of cultivated fields, fallow fields and rough pasture. The pasture areas consist of land on which crops cannot be grown because the loose soil is shallow with rocky outcrops. This land is grazed in all seasons while crop fields are only grazed after the harvest until sowing in the following year. Fallows are generally grazed in all seasons except when they are surrounded by crop fields. The Fakara also features strong inter-annual land use dynamics. Thus a field cultivated in one year may be left fallow in the following year and vice versa. Estimation of plant productivity must take all these parameters into account in the sampling of the sites, making assessment a little more complicated than in the Gourma. As in the Gourma, the variable measured in the field is the aerial mass of the herbaceous stratum measured in 1 m × 1 m squares chosen at random along homogeneous transects for fallow and grazing zones. The zones under crops are sampled by planting hole or plant with density measured in parallel (Hiernaux *et al*., 2009 a). The division of the landscape in this region makes it necessary to use transects 200 m long in fallows and grazing areas and 100 m for crop fields (in comparison with 1 km for the Gourma sites). Finally, the historic depth in the dataset is a little shorter as the collection of field data started in 1994. However, this means 17 years of comparison with satellite data.

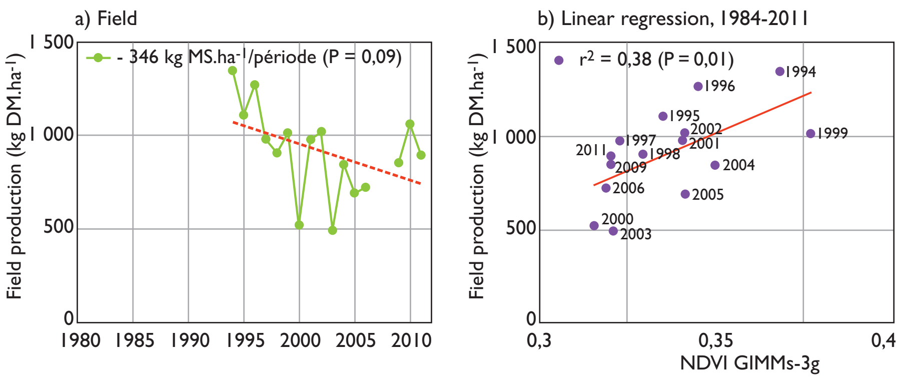

Figure 5.
a) The temporal evolution of field data (mass of the herbaceous stratum) averaged from the sites in the Fakara in Niger, from 1994 to 2011.
b) Correlation between field data and NDVI GIMMS-3g data from 1994 to 2011.
Source: adapted from Dardel et al. *(2014 b).*

The temporal trends calculated from averaged field data for the Fakara region also confirm the trend observed in the NDVI averaged for the same zone: the average of the masses measured at the different sites displays a negative trend from 1994 to 2011 (Fig. 5a). Agreement between field and remote sensing data is not as good as for the Gourma in Mali (R^2 = 0.38, Fig. 5b). This can be explained partially by the greater heterogeneity of the landscape and strong land use dynamics. Nevertheless, the important thing is that there again there is also coherence between the two totally independent datasets. It is obviously important to identify the cause of these trends—that are increasing in the Gourma and in most of the Sahel but decreasing in the Fakara.

Can these trends be explained by the evolution of rainfall?

In semi-arid regions like the Sahel, the main explanatory factor of plant production is the amount of rainfall received by the ecosystems: in years of rainfall deficit production is very small or nil in extreme cases. The relation between production and rainfall may be modified if other factors disturb the rainfall/production relation (for example, factors related to human activities such as land clearance, deforestation, the formation of soil crust, salinisation, fires, livestock, etc.). Here, we examine the link between plant production and rainfall measured in the field using recording rain gauges in the Gourma in Mali and the Fakara in Niger.

The Gourma, Mali

Rainfall in the Gourma region increased very strongly from 1984 to 2011, as is shown by the measurements from a network of recording rain gauges covering the region and whose annual cumulation anomalies are shown in Figure 6a. The increase was some 5 mm per year throughout the period 1984-2011. Strong correlation is observed between production of the herbaceous stratum averaged over the region and precipitations: 76% of inter-annual variability of production is accounted for by the evolution of rainfall (Fig. 6b).

The following question is raised: can the regreening of the Gourma be accounted for by the recovery of rainfall during the same period?

Rain Use Efficiency (RUE) is frequently used as an indicator to separate the influence of rainfall on plant production from other potential factors. It describes the efficiency of rain use by plants. It is calculated simply as a ratio of annual production to rainfall. Theoretically, if the environment is not changed as time goes by, rain use

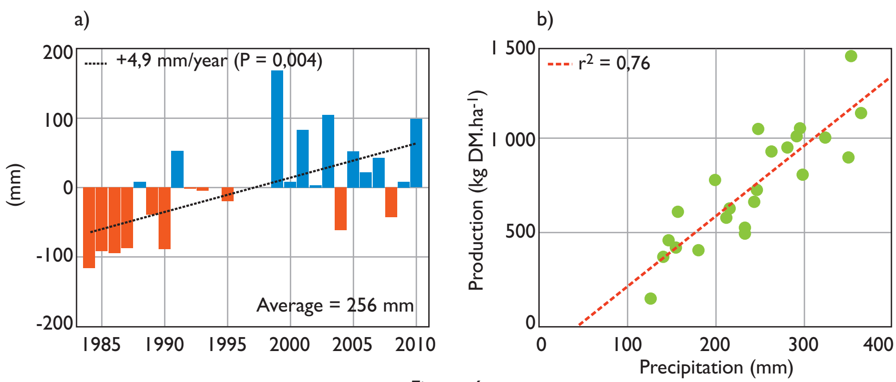

Figure 6.
a) Anomalies in annual precipitation measured in the Gourma region from 1984 to 2011.
b) Correlation between production measured in the field and precipitation.
Source: Dardel et al. (2014 b). Data provided by DMN (Direction de la météorologie nationale) Mali.

efficiency for pant growth should remain unchanged (Le Houerou, 1984). In contrast, if ecosystems are changed by a factor of some kind, and especially if they are degraded, rain use efficiency decreases. This decrease in RUE in time is used as an indicator of ecosystem degradation.

Calculation of RUE trends for the Gourma region as a whole does not show any decrease against time (Fig. 7). On the contrary there is a slight trend for an increase but this is not statistically significant (P = 0.29). Analysis of the RUE at the scale of the region thus confirms that since the early 1980s there has been no degradation of Gourma ecosystems—or at least those that are accessible by satellite observation. However, it is seen in Chapter 9 that these conclusions should be modulated when a finer spatial scale is examined: it is possible, in fact, to detect degradation of the vegetation in a small fraction of the landscape—in certain surface soils—while the overall signal for the region remains that of pronounced greening.

We can thus affirm today that regreening has occurred in the Gourma and that the direct cause is a partial recovery in precipitation after the major droughts of 1983-1984. At a closer scale, mechanisms that are still not well known may nevertheless affect plant production in part of the landscape but without modifying the overall regreening signature.

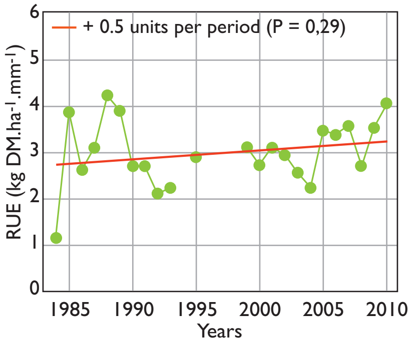

Figure 7.
Evolution of RUE (Rain Use Efficiency) in time,
calculated as the ratio of plant production measured in the field to annual rainfall
(cumulated during the growth season, that is to say from July to October).
Source: Dardel et al. *(2014 b).*

The case of the Fakara in Niger

The rainfall trend during the past two decades is not as clear for the Fakara region. The slight increase observed between 1990 and 2011 is not statistically significant and the same applies to the slight negative trend observed during the period 1994-2011 (Fig. 8a).

Correlation between plant production measured in the field and rainfall measured by recording rain gauges is much poorer than for the Gourma region (R^2 = 0.07, Fig. 8b).

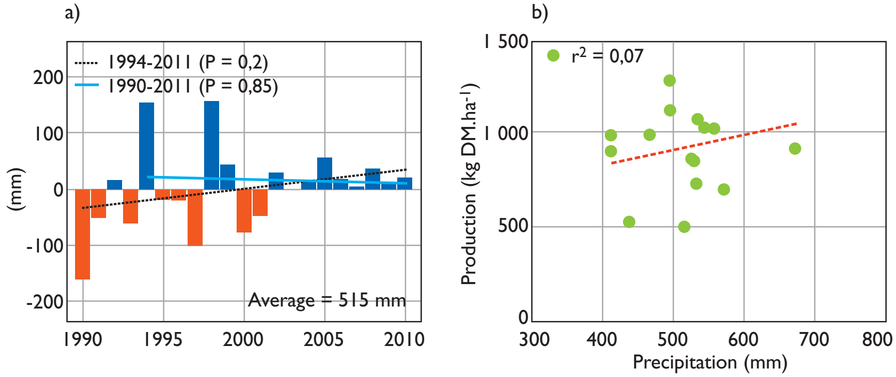

Figure 8.
a) Anomalies in annual precipitation measured in the Fakara region from 1990 to 2011.
b) Correlation between production measured in the field and precipitation from 1994 to 2011.

However, the rainfall records used here do not correspond totally with the Fakara region where vegetation is monitored as the data used were collected in the Niamey square degree, which is a larger zone.

As for the Gourma, analysis of RUE trends should make it possible to describe the influence of precipitation on plant production. For this, RUE trends were studied with separate examination of three types of land use: cultivated fields, fallows and rangelands. Only fallows stood out among the three types of land use as it was the only one to feature a decrease of RUE in time (Fig. 9). This means that the evolution

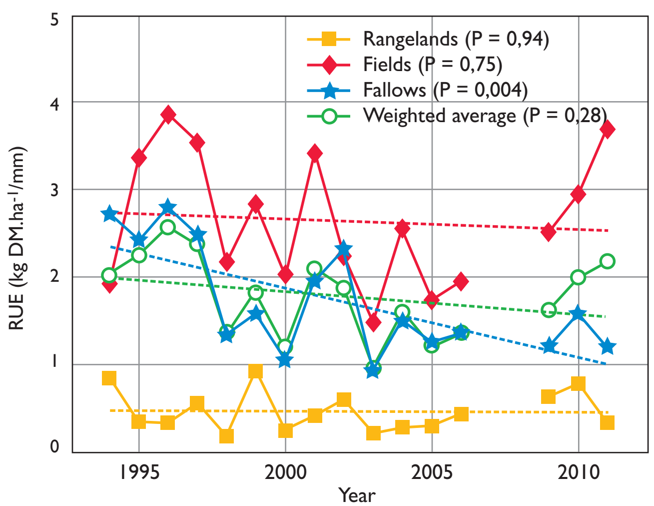

Figure 9.
Evolution of RUE in time (estimated from field measurements of herbaceous plant mass and rainfall) in the Fakara region from 1994 to 2011.

of herbaceous plant production in fields and rangelands is clearly accounted for by the simultaneous evolution of precipitation while the areas under fallow seem to display a decrease in plant production that is not explained by the evolution of rainfall. More in-depth analysis (using high spatial resolution images for example) would be necessary to confirm this preliminary diagnosis and then to better understand the cause of the different evolutions. For example, one hypothesis might be that the strong increase in local population and the substantial cultivation of land has diminished soil fertility via the acceleration of fallow/crop rotation mechanisms (with a reduction of the longest fallows) and the cultivation of less fertile land, but this remains to be confirmed.

Simulation of herbaceous plant production in the Gourma during the period 1950-2012

Models are the most appropriate tools for setting the trends observed using in *situ* measurements and remote sensing data for a longer period, in particular going back to the 1950-1960 wet period. Some of the data accessible are discontinuous, such as aerial photographs, Landsat images and the first field observations (BOUDET, 1972) but are often insufficient for reconstructing long trends. The STEP vegetation model (MOUGIN *et al*., 1995) was therefore used to simulate the evolution of herbaceous biomass in the Gourma over the period 1950-2012. Rainfall variability is the only variable used to run the model as a series of homogeneous rainfall data measured at the Hombori meteorological station in central Gourma for 1950-2012 is available. The other input parameters (incident short-wave radiation, air temperature, relative humidity and windspeed) were set for each year at their daily values measured at the Agoufou meteorological station in 2006, used within the framework of the AMMA programme. Sensitivity analysis showed that approximately 90% of inter-annual variation of vegetation is covered in this way.

The production of herbaceous mass simulated by STEP is well correlated overall with precipitations (Fig. 10) but the relation is less linear for rainfall greater than 400-500 mm per year. During the period 1984-2010, correlations with simulated production ($R^2 = 0.50$) were weaker that those calculated using in *situ* data ($R^2 = 0.76$, Fig. 6b). The difference might result at least partly from the fact that the Hombori is in central Gourma and the simulation does not take into account the more arid locations in the north where the growth of vegetation should be even more dependent on available soil moisture.

Precipitation measured at Hombori station and used as input for the STEP model and the figures for green biomass given by simulations, together with their trends during different periods, are shown in Figure 11 and summarised in Table 1. The effect

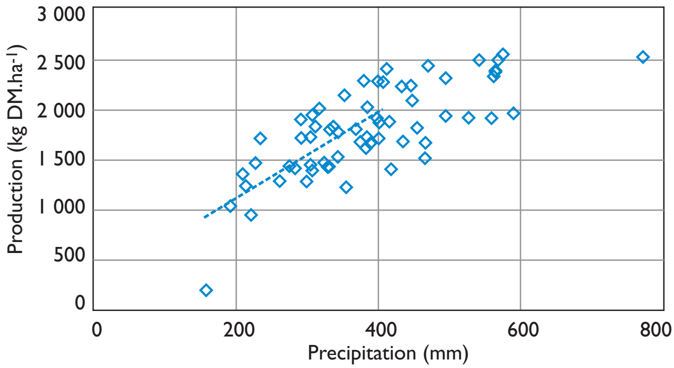

Figure 10.
Relation between biomass simulated by STEP (annual maximum) and precipitation (cumulated annual figure).

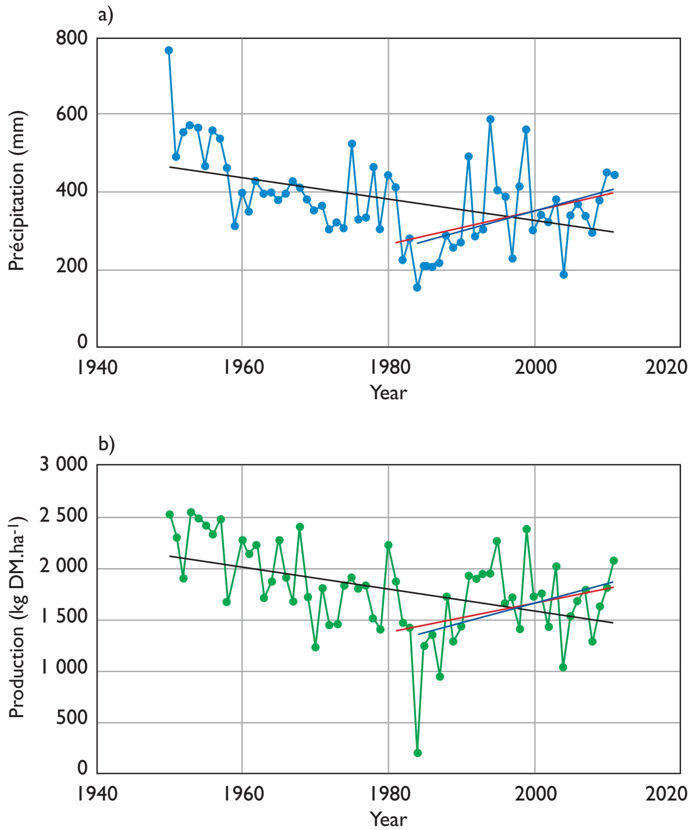

Figure 11.
a) Precipitation and b) green biomass simulated by STEP and their trends during the periods 1950-2012 (black), 1981-2011 (red) and 1984-2011 (blue). All the trends are statistically significant ($p < 0.05$ in Student's Test).

of the extremely severe droughts (1984 and 2004) is clearly marked in vegetation productivity, which shows a very pronounced minimum in 1984. The trends drawn from modelling agree closely with those drawn from field observations and remote sensing for the period during which the *in situ* and NDVI data are available. In particular, a significant regreening signal is observed from 1981-1984 which, as has already been mentioned, is to be ascribed to the recovery of precipitation during this period.

In contrast, examination of a longer period that includes wet years (1950-2012) shows negative trends in both precipitation and biomass simulated by STEP. This is a sign that in parallel with precipitation that is still smaller than during the wet period the ecosystem was unable to attain the strongest biomass levels of 1950-1960.

Tableau 1.
Comparison of STEP simulation trends in precipitation and biomass and the trends observed using NDVI observations and in situ *herbaceous mass data. All the trends are statistically significant ($p < 0.05$ using Student's Test).*

Period	**Precipitation trends at Hombori met. station** (mm/period)	**Trends in biomass simullated by STEP** (kg DM.ha^{-1}/period)	**Trends in biomass observed by remote sensing** (NDVI units/period) Source: DARDEL *et al.* (2014 a)	**Trends in biomass measured *in situ*** (kg DM.ha^{-1}/period) Source: DARDEL *et al.* (2014 a)
1950-2011	- 167.4	- 821		
1981-2011	+ 134.2	+ 552	+ 0.032	
1984-2011	+ 146.2	+ 654	+ 0.05	+ 626

What is the future for Sahelian systems?

This work shows that there has been an overall regreening of plant cover throughout the Sahelian region in the last 30 years although there are a few regions where plant cover trends are negative, as in the Fakara in Niger and the central parts of Sudan. Satellite observations were found to be a robust method for detecting changes in plant cover over long periods of time as they match the changes observed in the fields in two regions with opposite trend signs (the Gourma in Mali and the Fakara in Niger).

However, low-resolution satellite observations such as AVHRR data are not sufficient for gaining understanding of all the mechanisms involved, as for example in the Fakara in Niger or at a scale of less than one AVHRR pixel. More in-depth analysis of these changes requires the use of other facilities such as very high spatial resolution satellite images and above all networks of field observations that provide information about numerous parameters that are difficult to observe from space—composition of the flora, grazing pressure, etc.

In examination of the production trends imposed by climatic trends, it is important to bear in mind that they are closely dependent on the spatial and temporal scales considered, especially for diagnosis of the 'state of health' of vegetation in comparison with a reference situation (e.g. the beginning of the period for trend studies). We have shown that the regreening observed in the Gourma region over the past 30 years has been caused mainly by the recovery of precipitation during this period, and this is probably the case for the whole of the Sahel. However, it is probable that a small part of the landscape (such as the surface soils in the Gourma, see Chapter 9) may be subject to degradation via mechanisms that are still poorly known. These contrasted trends are not in opposition with each other as they involve different scale factors.

The simulations performed using the STEP model allowed us to reconstitute the evolution of herbaceous plant cover for more distant periods—in this case since the 1950s. The results of these simulations show that the vegetation has not recovered to levels as high as those before the 1970s and 1980s droughts, in parallel with precipitations that are also not at the same level as in 1950-1960.

In this context, one might legitimately wonder about the evolution of precipitation in the coming decades. For this, only modelling can give a few lines of approach but climate models diverge and do not give either the trend or intensity of the changes to be expected with any certainty. The regreening observed today must therefore not mask stronger variability or lead to forgetting the possibility that this may be just a transitory state of the vegetation in a context of change or of climatic variability in which forecasting is delicate, especially as regards precipitation.

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Chapter 7

Anthropic and environmental factors involved in the increase in flooding in the Sahel

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Introduction

The hydrology of the Sudano-Sahelian strip has evolved rapidly in recent decades. West Africa has experienced strong climatic and environmental changes that have deeply modified the runoff/infiltration/evapotranspiration balance and, as a result, the conditions of flow formation.

The observations and scientific progress that have enabled better understanding of the impact of environmental changes on the hydrological cycle can be summarised in the form of several key stages. During the fieldwork conducted for his doctoral thesis, Albergel (1987) noted that since (and in spite of) the start of the drought, discharges were increasing in the ORSTOM experimental catchment areas in Burkina Faso and located in the Sahel zone but—more logically—were decreasing in those in the Sudanian zone. A few years later, Olivry *et al.* (1993) and Olivry (2002) showed that the discharge of the Upper Niger at Koulikoro (drainage basin of 120,000 km²) and numerous large West African rivers were decreasing twice as fast as the decrease in precipitation. This was corroborated for the region as a whole by Mahé *et al.* (2003, 2005, 2009, 2011, 2013) and by Amogu *et al.* (2010) who showed the break between 'Sahelian' behaviour (increase in discharges in spite of the drought) and 'Sudano-Guinean' behaviour (the decrease in discharges was greater than that of rainfall). The revealing of the regional coverage of the increase in discharges since the start of the drought has led to talking of 'the hydrologic paradox of the Sahel' (Descroix *et al.*, 2009; Descroix *et al.*, 2013 a). Meanwhile, Casenave and Valentin (1989) had shown the prime role of 'soil surface features' in the formation of runoff, and Leduc *et al*. (2001) had defined the 'Niamey paradox': the increase in groundwater level since the beginning of the drought in the Niamey square degree. This was an indirect effect of the increase in flows (associated with changes in surface features caused by the environmental changes); so far it has only been seen in the aquifer of CT3 (Continental Terminal 3) in the Niamey zone[1].

The following features can be contrasted schematically:

− a Sudano-Guinean zone in which the flow regime has not (yet?) been modified by changes in the environment. The functioning of soils and drainage basins is such that runoff only occurs when the soil is saturated. The decrease in precipitations does not affect soil water holding capacity and plant cover—even when changed—remains dense and takes up the same quantity of moisture as before; only the fraction of rainfall that turns into runoff is therefore concerned by the decrease in precipitation. This explains why the decrease in discharge is stronger than that of precipitation;

− a Sahelian zone in which runoff is caused increasingly by rainfall intensity exceeding soil infiltration capacity, as soil surface crusting very soon results in the saturation (from the top in this case) of soil that no longer has retention capacity. The 'Sahel paradox' is caused by this loss of infiltration capacity. Bare soil and the shortening of fallows cause damage. Among others, Albergel and Valentin (1988), Valentin and Bresson (1992) and Ambouta *et al*. (1996) have shown that this fosters the formation of surface crust. In sectors in the northern Sahel where the recovery of vegetation has been observed since the end of the periods of the greatest shortage of rainfall (mid-1980s), the soil cannot recover in rocky areas where it was constituted by lithosols and regosols, and held by existing vegetation (Hiernaux *et al*., 2009; Gardelle *et al*., 2010).

This increase in the discharges of Sahel streamflows observed since the beginning of the West African drought seems to be becoming more marked since around the mid-1990s, with a modest recovery of the total annual rainfall recorded. It is therefore not possible to talk in terms of a paradoxical situation since the end of the 1990s and the recovery of precipitation. This logically further increased runoff. Indeed, in the past few years—since the mid-2000s—the increase in the volume of annual floods and an increase in flooding on Sudano-Sahelian West Africa have been observed. (Descroix *et al*., 2012; Sighomnou *et al*., 2013).

Beyond the question of the Sahel hydrologic paradox, this chapter addresses the question of how natural and human factors cause the increase in flooding in the region. It is seen that a possible intensification of precipitation is not yet sufficiently marked to account for discharges that are much higher than in the 'wet' decades from 1950 to 1970. Conversely, the urbanisation of flood risk zones explains why floods are more serious than before. Finally, the increase in runoff aggravates the already marked erosion of Sahel soils and an increase in solids loads and sedimentation:

1. Extension towards eastern Niger, consisting of measurements of the groundwater level in half a dozen more locations on the Zinder road where 6-monthly visits had been started in 2006 within the framework of the AMMA programme. These measurements were suspended in 2008 at the request of the AMMA hydrogeologists but the groundwater level increased for three years (2005-2008), that is to say at least to the longitude of Maradi.

these features caused the opening up of endorheic basins (MAMADOU *et al.*, 2015) and the silting up of waterbeds by sand carried from slopes (AMOGU *et al.*, 2010), two complementary factors in the increased severity of floods.

An increase in flows that has led to increased risks of flooding

It has been shown that a basic tendency for an increase in runoff coefficients can be attributed to changes in land use, and in particular the very significant increase in the areas of crusted soils.

An increase in flood events in the recent years has been highlighted in both the south Sudanian zones (TSCHAKERT *et al.*, 2010) and the Sahel regions (TARHULE, 2005). Indeed, in 2005, Tarhule used a study of newspapers to show that floods were becoming more severe in terms of their scale and the damage caused; he showed that the distribution of floods reported in the press in Niger was mainly linked to elevation and to the spatial distribution of the population. Following the serious floods that hit southern Burkina Faso and northern Togo and Ghana in 2007, the study by TSCHAKERT *et al.* (2010) highlighted the recurrence of floods in West Africa, a phenomenon to which insufficient attention had been paid and that should now be taken into consideration.

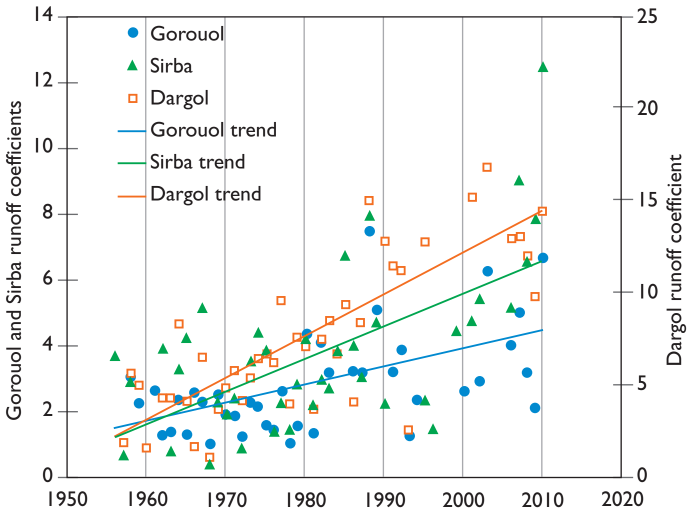

Figure 1.
The increase in runoff coefficients of the drainage basins of right bank tributaries of the River Niger.

Furthermore, Di Baldassare *et al.* (2010) showed that floods were causing increased damage in West Africa; the scale of human losses had increased since 1950, partially explained by population growth—especially in towns—which in itself makes societies much more vulnerable.

Following the observations by Albergel (1987) and Olivry (2002), Descroix *et al.* (2012) and Sighomnou *et al.* (2013) showed that changes in land use and the 'fatigue' of the latter are the main explanation of the considerable increases in discharges from the Sahel drainage basins and in flooding. Thus, it is shown in Figure 1 that the discharge coefficients of the catchments of the right bank tributaries of the Niger in the Sahelian region have tripled since the beginning of the drought at the end of the 1960s. Figure 2 shows the interdecadal evolution of the two annual floods of the Niger at Niamey, clearly indicating the contrary pattern:

− the first flood of Sahelian origin occurs during the winter season and is linked with discharges resulting from monsoon rains whose intensity is generally high (35 % of rainfall displays intensity of more than 60 mm per hour). This flood is increasingly early; it reaches Niamey 40 days earlier than it did about 40 years ago. It is also increasingly separated from the second, main flood—the Guinean flood;

− and the second flood, referred to as the Guinean flood, that results from the arrival of flows generated in the upstream catchment by the same monsoon and that take several months to travel the 2,000 kilometres from Guinea, and above all the inner delta of the Niger, a vast area consisting of 120,000 km² of lakes and marshes in which the river loses an average of half of its discharge each year. After decreasing considerably during the dry years (1970 to 1990), the peak of this flood has clearly

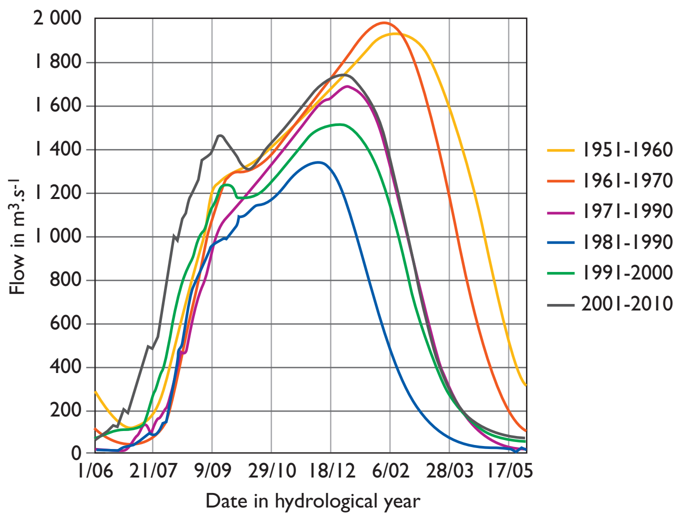

Figure 2.
Inter-decadal evolution of the hydrograph of the River Niger at Niamey:
increasing earliness of the first flood and a drastic decrease in the duration of the second.

recovered since the 1990s but is still far from reaching the volumes observed before the drought. Above all, the main flood is still more than two months shorter than it was during the wet decades as a result of the very strong decrease in flows in the upstream catchment. In terms of resource, the quantities of water have therefore been most affected during the dry season as low water is reached much earlier than before (Fig. 2).

The recent doctoral theses of AMOGU (2009), SOULEY YÉRO (2012) and MALAM ABDOU (2014) confirmed the substantial decrease in plant cover during the last few decades, the first examining the Sirba and Gorouol catchment (Fig. 3), the second the square degree of Niamey, the third the Dargol catchment, together with expected consequences of a decrease in water retention capacity of soils and catchments and an increase in flow coefficients. This research corroborates the evolution of plant cover at the regional scale as shown in the maps plotted by FENSHOLT and RASMUSSEN (2011).

A climatic factor: the increase in the number of rainfall events with high cumulated depths

However, it seems that the occurrence of high daily amount rainfall events is increasing. This would help to explain the increase in flow and runoff coefficients.

To check this working hypothesis, a statistical study of rainfall with high daily amounts was conducted in two areas in Sudano-Sahelian West Africa: Senegal (DIONGUE *et al*., submitted) and the mid Niger River basin (DESCROIX *et al*., 2013 b). The locations of the two study sectors, at the same latitude, are shown in Figures 3 and 4.

It is seen in Figures 5 and 6 that the number of events with the greatest amounts is increasing and, in the Middle Niger Basin, closely approaching the ones observed during wet decades. This is already the case of events with depths of more than 60 mm. Earlier onset of the flood is also observed and might be linked to the combination of soil crust (human cause) and the increase in the occurrence of extreme pluviometric events (climatic cause, possibly to be linked to climate change, itself resulting mostly from anthropic activities), especially at the beginning of the rainy season (in May and June and, less significantly, in July) (DESCROIX *et al*., 2013 b). DIONGUE *et al*. (submitted) noticed the same evolution in Senegal. However, in spite of a strong increase in events with considerable cumulated depths (up to more than 60 mm per day), the maximum values observed from 1950 to 1968 have not yet been reached in Senegal at any station in any season.

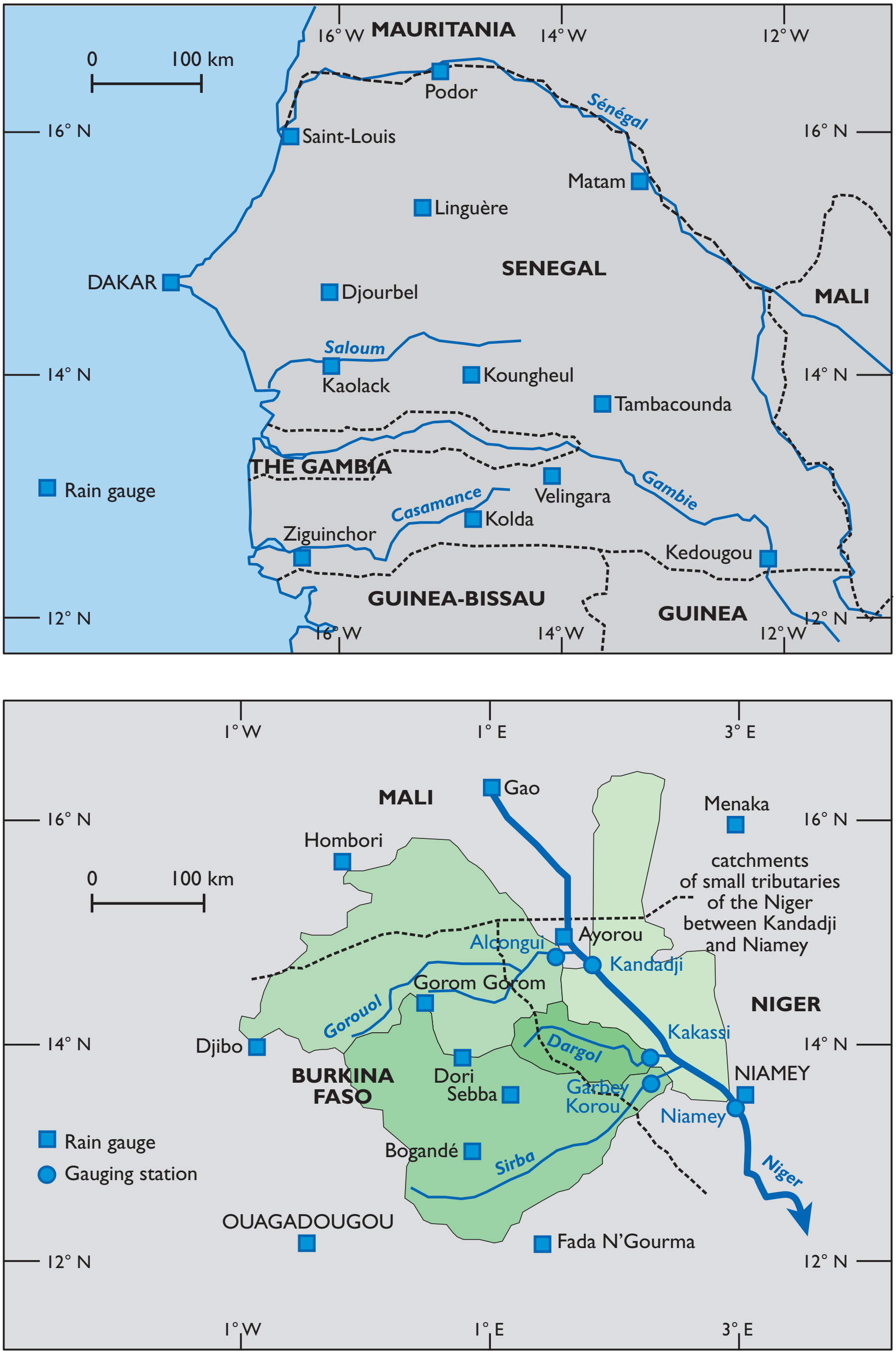

Figure 3.
Schematic map of Senegal (top) and the middle Niger basin (bottom).

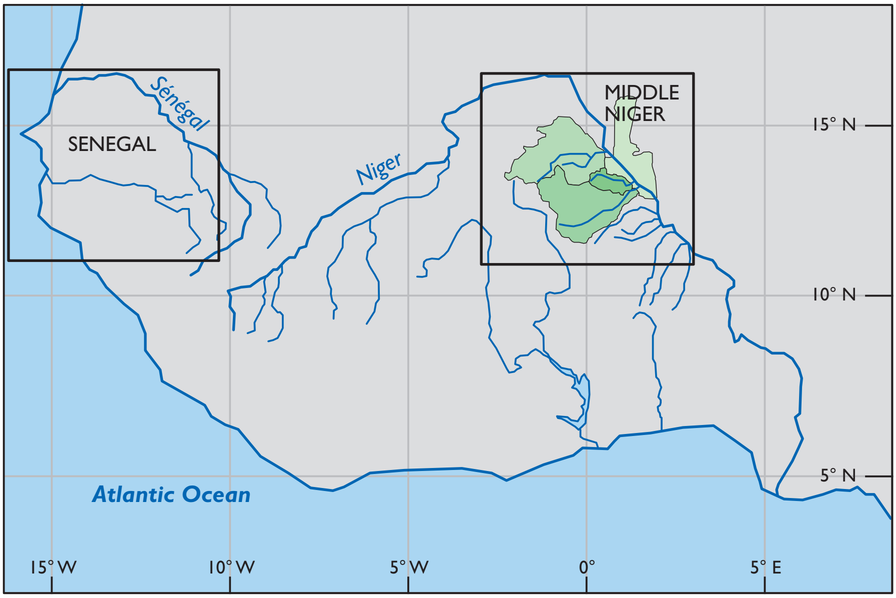

Figure 4.
Position of Senegal and of the middle Niger basin, at the same latitudes.

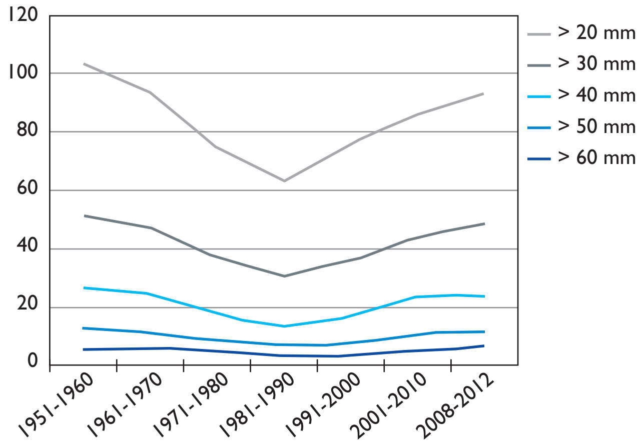

Figure 5.
Number of events by decade and cumulated rain fall depth category in the Middle Niger Basin.

This tendency in Senegal is shown in Figures 7 and 8.

Finally, PANTHOU (2013) analysed daily rainfall in a window running from 10°W to 5°E and from 10° to 15°N (partially including the Middle Niger Basin mentioned above) to study the evolution of extreme precipitation. He showed that there had

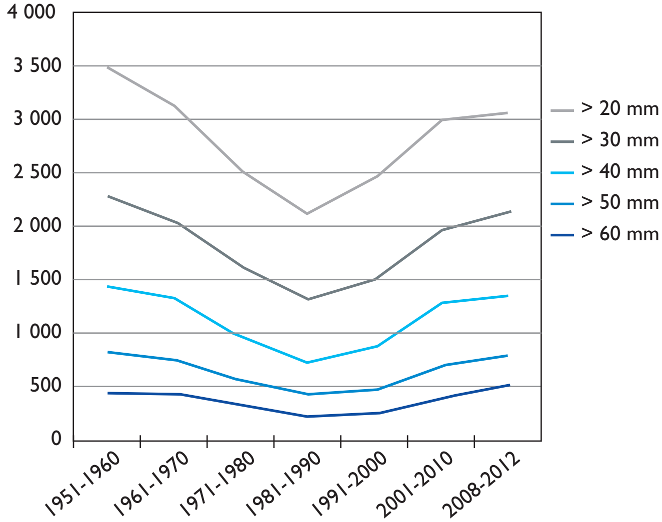

Figure 6.
Rainfall in mm per year and per category in the Middle Niger Basin.

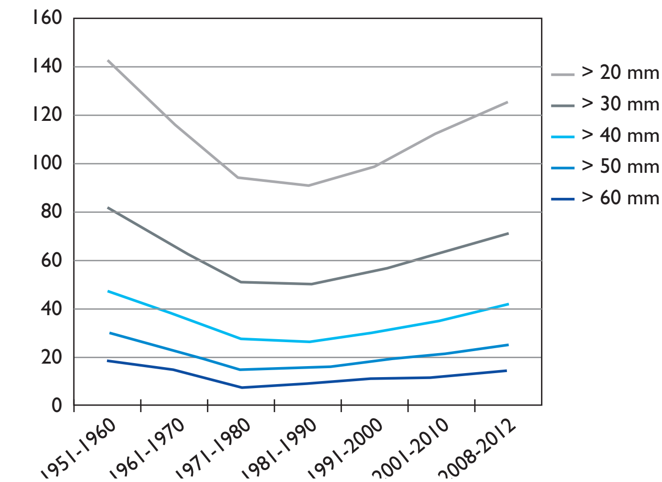

Figure 7.
Number of events by decade and cumulated rainfall depth category, Senegal.

been a recent increase in the number of 'extreme' rainfall events since the decade starting in 2001. Furthermore, PANTHOU *et al.* (2013) showed the decrease in the number of these events during the period of shortage of rainfall and its recent increase (see in particular Chapter 2).

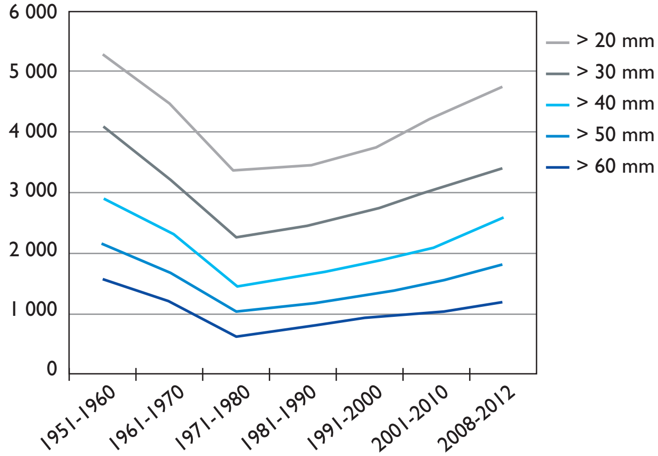

Figure 8.
Rainfall in mm per year and per category, Senegal.

An 'urban' explanation

Urbanisation can account for the increase in risk of flooding as it is accompanied by the processes described below.

Impermeabilisation of urban and peri-urban zones

This is caused by most of the 'urban' features: roads, buildings, other impermeabilised surfaces such as pavements, car parks, sports grounds, etc.

The reduction of the areas of possible infiltration zones for rainwater is a well-known factor in the increase in flow coefficients. It caused the flooding of the northern districts of Bamako on 28 August 2013; it originated in a 85 mm of precipitation event, a 3-year return period events; however, uncontrolled urbanisation of the hills above the Banconi district generated flows led to extensive damage (Fig. 9).

However, purely urban floods affected zones that have been built-up for a long time and that had not been flooded before. This was the case in particular of the events of 1 September 2009 in Ouagadougou and 26 August 2012 in Dakar (Fig. 10). In both cases, the increase in runoff causing flooding was purely urban. As a result, an increase in the occurrence of intense precipitations (see above) should be argued as being the cause of these events. Indeed, the latter floods took place in towns that do not have watercourses but do have areas that have been urbanised for a long time. The most intense rainfall events in recent decades did not cause such flows and hence such damage.

Figure 9.
The cluttered bed of one of the two streamflows that overflowed and flooded the Banconi district in Bamako on 28 August 2013.

Figure 10.
The construction of drains whose absence caused the flooding of the Ouest Foire district of Dakar on 26 August 2012 (photo taken in December 2013).

The urbanisation of areas with a flood risk

The other major impact of urbanisation is that it makes vulnerable populations who were safe before. Indeed, while urbanisation was at least partly the cause of the Bamako 2013 flood, uncontrolled urbanisation is seen frequently in zones not classified for development ("*non aedificandi*") such as zones with a flood risk for example. As indicated by Di Baldassare *et al*. (2010), the increase in the population and the strong urbanisation of countries in sub-Saharan Africa form one of the main components in increased losses and human victims as a result of flooding. Niamey has been hit by three flood events in four years, indicating both the increase of flows—and hence increased risk—and of the vulnerability of the population which is left to settle in forbidden flood risk zones as the authorities have not planned sufficient area for housing the many new arrivals. A study performed by the NBA (Niger Basin Authority) (Sighomnou *et al.*, 2012) shows the maps of floods plotted by the NBA with AGRHYMET (the CILSS training centre for agronomy, hydrology and meteorology in Niamey). It is shown that a large proportion of the right bank at Niamey flooded in recent years is in a zone considered to be at risk from floods.

The Niger reached its highest (at the moment) rainy season level in 2010 (it is reminded as mentioned above that the Sahelian flood is traditionally distinctly smaller than the Guinean flood). This level had only been exceeded twice since the beginning of recordings in 1929: during the 1968 Guinean flood and then during that of 1970. Extensive damage was seen as a result of the spontaneous urbanisation in an ancient riverbed of the Niger, clearly visible in Figure 12. Discharge had reached 2,080 $m^3.s^{-1}$. In 2012, the flood twice reached a discharge not observed since 1929, for both yearly floods (Sahelian and Guinean). Indeed, the discharge exceeded 2,400 $m^3.s^{-1}$ (max. 2,480 $m^3.s^{-1}$) on two occasions. The damage was even more serious, and at least 50 people died, without counting the tens of thousands of people made homeless as a result of the destruction of their houses by floodwater and the wetting of the banco (adobe) that most dwellings are built of. Most of these collapsed, with numerous victims. The third flood was in 2013 and almost as severe as that of 2012 and in any case higher than that of 2010, reaching a flow of 2,420 $m^3.s^{-1}$ at its peak. However, must less damage was caused as the area flooded in 2012 was not yet inhabited again.

An acceleration of hydrologic and sedimentary processes

The case of the city of Niamey is emblematic of the deep-seated environmental changes suffered by the Sahel for several decades. Land clearance and soil fatigue is seen in the land examined upstream in the catchment areas of the tributaries of the River Niger (see first part). We know that there has been an increase of rainfall events with considerable cumulated depths for several years (see second part); finally, the recent floods have affected districts with often spontaneous building in flood zones but that had not been flooded for several decades among other reasons because of the regional deficit in rainfall mentioned in the third part.

Here, in the final section, we address two hydrologic and hydrographic processes observed recently: the silting up of riverbeds and the increased exorheism.

The silting up of riverbeds (the case of the River Niger)

This can have resulted in floods whose downstream discharge had been observed in the past but without overflowing. The soil erosion phase in the Sahel since the beginning of the drought has considerably increased solid loads. The materials carried tend to be deposited in the beds of stream flows (of the Niger when koris (wadis) are direct tributaries of the river). The cross-sectional area thus decreases considerably, causing overflowing at discharges markedly smaller than those required previously. Figure 11 shows the intrusion in the riverbed of the alluvial cone of the Kourtéré, a right bank tributary of the Niger that joins the latter just upstream of Niamey and its advance over the years, as reported by AMOGU *et al.* (2010); this reduces the cross-sectional area of the bed, making overflowing more probable during large floods.

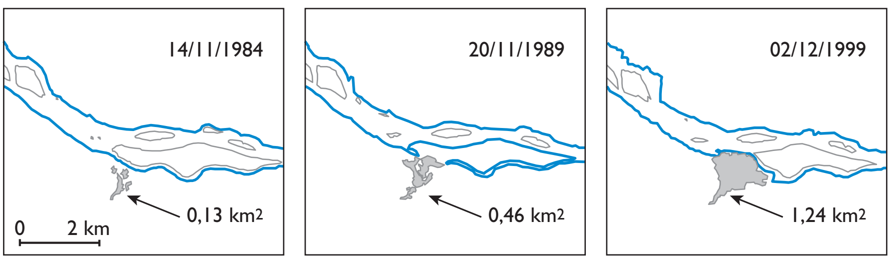

Figure 11.
Advance of the alluvial cone of the Kourtéré kori from 1984 to 1999.

Increased exorheism

This small tributary (catchment area 350 km²) is an excellent illustration of the process of the spread of exorheism as observed for several decades in the Middle Niger Valley (MAMADOU *et al.*, 2015). CHINEN (1999) showed that the catchment area of this kori was endorheic until the 1950s and that it pierced the sandy ridge that held the water body in 1975 at the latest (according to IGNN aerial photography). It was only then that this wadi became a tributary of the Niger.

MAMADOU *et al.* (2015) also showed recently that changes from endorheism to exorheism have led—along the course of the Middle Niger again—to an increase in the area of the active catchment area of the river that, with the same discharge coefficient, contributes to increase the flows to be discharged. Figure 12 shows the positions of the observed or supposed failures of endorheism that have occurred in recent decades in this part of the Niger Valley.

Without making a judgement on failures that may exist elsewhere, it can nonetheless be supposed that they are numerous in the Niamey region because of the serious degradation of the environment observed there (CHINEN, 1999; AMOGU *et al.*, 2010; MAMADOU, 2012; MAMADOU *et al.*, 2015). Indeed, the land clearance observed throughout the Sahel—aggravated here as population growth is greater than elsewhere—is complemented by clearance to cover urban firewood and construction timber requirements and over-grazing by numerous herds waiting to reach the urban market.

Intense erosion and hydric dynamics are therefore observed around Niamey (although BOUZOU MOUSSA *et al.* [2009] record that such processes are also found 300 km east of Niamey); this is shown by new koris (neo-exorheism) visible in the landscape as sharply cut, new trenches in dunes and sandy soils and by large and extremely active alluvial cones that obstruct the bed of the Niger more every day around Niamey. Crusted, runoff surfaces are becoming larger and the new small Niger tributaries add very significant areas because of the high runoff coefficients observed. Unfortunately, these observations made on the Middle Niger are confirmed throughout almost the entire Sudano-Sahelian strip.

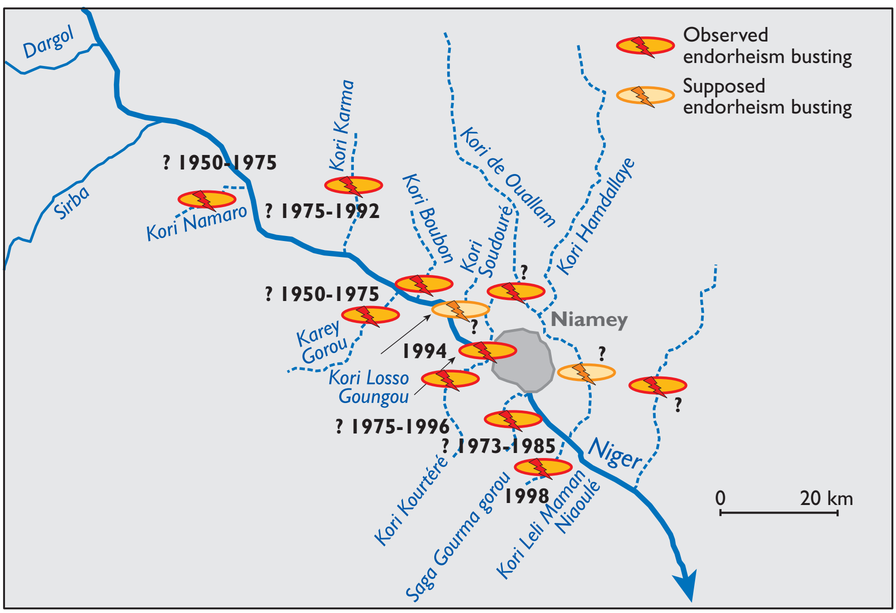

Figure 12.
The positions of certain endorheism bursting phenomena
that have resulted in an increase in the exorheic zone feeding the River Niger.
The date of the endorheism bursting is indicated when known.

Conclusion

The recent floods of 2007 (northern Ghana and Togo, southern Burkina Faso), 2009 (on 1 September precipitation at Ouagadougou was 270 mm in less than 24 hours and on the same day the embankments of wadi Teloua failed and flooded Agadès), repeated overflowing of the River Niger at Niamey (in 2010, 2012 and 2013), floods at Dakar (26 August 2012 when the city had the second highest 24-hour rainfall since the beginning of records but the highest in hourly intensity) and Bamako (28 August 2013) seem to indicate an increase in the risk of flooding in Sudano-Sahelian West Africa. The experience gained by AMMA shows that changes in land use are the main driving force behind the 'Sahel hydrologic paradox'. But more or less recent processes are aggravating the process:

− we observe an increase in high daily amount rainfall events with high cumulated depth, both in the west (Senegal) and the centre of the Sahel (Middle Niger Basin);

− urbanisation causes the impermeabilisation of rainfall areas, increases runoff coefficients and may account for the forming of strong urban currents;

− furthermore, the uncontrolled urbanisation of increasingly large areas aggravates the effects of flooding, making the population—and especially the poorest people—very vulnerable to flood risks;

− the power of the floods, and especially those generated in the Sahel zones, may be increased by the ongoing increase in exorheism, with historically endorheic areas becoming exorheic after the failure of sand ridges and overflowing from ponds;

− finally, increased erosion in Sahelian zones, and especially failures of endorheism, cause the rapid formation of vast fans of sediment in the beds of major rivers, reducing their cross-sectional area and facilitating overflow and floods.

Decision makers must take into account these many factors as all seem to be displaying adverse trends and could make flow management extremely delicate in Sahelian zones and particularly in urban areas.

Scientists and decision makers have focused their attention on the long drought period in West Africa, without knowing if it is really over. But during the years of deficit the risk of flooding has worsened to the extent that the recent relative increase in annual precipitation could make it dramatic.

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Chapter 8

The forage constraint in pastoral and agropastoral livestock farming in the Sahel

Adaptation and prospects

Pierre Hiernaux, Mamadou Oumar Diawara, Laurent Kergoat, Éric Mougin

Introduction: the forage question

The forage question is involved in livestock farming practices in the Sahel and also in research conducted on the improvement of its profitability (Lhoste *et al.*, 1993; Klein *et al.*, 2014), animal husbandry development policies (Zoundi and Hitimana, 2008; CORAF/WECARD, 2010; Krätli *et al.*, 2013) and finally discussion of the future of animal husbandry in the Sahel (Peyre de Fabrègue, 1984; Hesse and Thébaud, 2006; Jullien, 2006; Bassett and Turner, 2007). The availability and quality of forage would seem to be the main constraint for the development of livestock farming, and the constraint for pastoral livestock operations would be the carrying capacity of rangeland (Boudet, 1984; Breman *et al.*, 1984, Le Houérou, 1989). However, at the same time the questions of forage and carrying capacity have been eluded substantially in development projects, as if the solutions were up to the judgements of farmers who, in their practices founded on knowledge that has been handed down, experience and the support of collective institutions, have always found a solution even during the worst situations of drought and access conflicts (de Bruijn and van Dijk, 1995; Thébaud and Batterbury, 2001; Krätli and Schareika, 2010). The definition and often the questioning of the livestock carrying capacity in the Sahel by technicians, scientists and political decision makers are revealing in this respect (Hiernaux, 1982; de Leeuw and Tothill, 1990; Sayre, 2008; Krätli *et al.*, 2015).

In fact the intuitive simplicity of the concept – the capacity of a pastoral resource consisting of rangeland and waterpoints to support a livestock operation in a sustainable manner (Boudet, 1984)—hides semantic duality. Indeed, the carrying capacity has 'zootechnic' meaning (Hiernaux, 1982) attached to the capacity of the pastoral resource to attain a livestock production objective: the maintaining of a certain level of fattening of livestock, of a certain level of milk production by lactating cows that give a certain reproduction level (age at first calving, fertility rate, limiting the death rate). The second meaning is described as being 'ecological' insofar as it is focused on the impact of livestock carrying capacity in rangeland, forage production capacity and, more broadly, the ecosystem services expected of the pastoral ecosystem: wood production, recycling of organic matter, infiltration of rain. The semantic duality results in confusion, especially as there is no obvious link between carrying capacities—each aspect depends on numerous conceptual variables such as the climate and fires—for forage production, species, breed and animal health for animal production capacity.

In addition, both meanings of the concept run into the strength of the seasonal and inter-annual dynamics of Sahelian forage resources. The extreme seasonal contrast, with the alternation of green prairies lasting for the few weeks of the rainy season and stretches of dry straw and litter that gradually disappear during the long months of the dry season, is considered as being inherent to the Sahelian ecosystem (Hiernaux and Le Houérou, 2006). But what forage production reference should be used to estimate livestock production capacity or to judge the degradation of rangeland in an ecosystem governed by a monsoon climate marked by very large variations in forage production resulting from rainfall variations from one year to the next (Le Barbé and Lebel, 1997) and rainfall with very irregular geographic distribution (Ali *et al.*, 2003), aggravated by runoff and flows (Breman and de Ridder, 1991)? The use of the 'zootechnic' meaning of the concept is complicated by the regional mobility of herds (Schlecht *et al.*, 2001) that is generally multi-specific. Mobility organised within the framework of community use of pastoral resources means that forage balances, the ratio of consumption to the quantity of forage available, is only possible for very large geographic areas used for grazing by a group of farmers whose herds may display very varied performances (Colin de Verdière, 1994). The seasonal mobility of herds also complicates use of the 'ecological' meaning of the carrying capacity, especially as the impact of grazing on vegetation and soils depends on both the intensity and season of grazing (Hiernaux and Turner, 1996; Hiernaux, 1998). Do these objective difficulties of implication mean that the carrying capacity concept falls definitively through a technical trap door (Krätli *et al.*, 2015)?

We seek here to answer the question in an empirical manner by trying to draw up a forage balance for a period of a few successive years at two locations in the Sahel: one where pastoral husbandry is the dominant economic activity at Hombori in the Gourma in Mali (Gallais, 1975; Boudet *et al.*, 1977; Ag Mahmoud, 1992) and a location where it is combined with the growing of millet and cowpea and numerous non-agricultural activities at Dantiandou in the Fakara in Niger (Osbahr, 2001). But it must be specified first of all what livestock systems are examined and how sensitive they are to the forage constraint. Balances are then drawn up with the successive quantification of forage availability and the consumption of forage by livestock at the two locations. The balances are then compared to the decadal tendencies in plant production and to the performances of the livestock operations. To conclude, the results are set in the development perspective of Sahelian livestock farms.

The diversity and interrelations of livestock systems in the Sahel

Livestock systems are very varied in the Sahel but generally pastoral insofar as the livestock feeds mainly or entirely by grazing in rangeland (Hiernaux and Diawara, 2014). The distinction made between pastoral and agropastoral livestock farming is more a reflection of the combining of crops and pastoral livestock rearing on the same family farm in the second case. The forms of regional mobility often used in pastoral operations are used to distinguish between sub-categories (Touré *et al.*, 2012; Turner *et al.*, 2014) depending on whether they involve the whole family (nomadism) or only the persons who move the livestock (transhumance) and the scale, regularity and even the direction of these movements. In contrast, the mobility of livestock in sedentary pastoral animal husbandry is limited to daily movements between resting places, watering and pasture suited to the season and the rights of access held by each livestock farmer (Turner *et al.*, 2005). However, breeding livestock farms produce young animals for specialised rearing markets (Hiernaux and Diawara, 2014). In breeding operations, males are generally sold young, with the exception of a few kept for reproduction whereas females are kept until the end of their reproductive career and then sold off. This is seen in the composition of herds in terms of sex and age. Females are markedly dominant at 75 to 85% and two thirds of these are adult. This is the case of cattle herds and sheep and goat flocks at Hombori and also at Dantiandou, but with the exception of small cattle rearing units in which young bulls for fattening and draught oxen are dominant (Fig. 1). Breeding is accompanied by secondary milk production. Indeed, milking often accounts for only a fraction of milk production so as not to slow the growth of calves, which remains the main objective (Zezza *et al.*, 2014). Milk and derived dairy products are for family consumption, with part being sold. The social issue of this is all the more important as this activity is generally reserved for women (Querre, 2003).

The great majority of the pastoral and agropastoral units in the Sahel are breeding operations, but there are also pastoral and agropastoral units that are not devoted to this and that can be grouped as a ‘specialised’ category. They purchase stock—often young animals—and rear it for use as draught animals that are then sold off (this is the case of the operations with less than 5 head of cattle at Dantiandou, Fig. 1), or for fattening (Ayantunde *et al.*, 2008) and finally but more rarely milk cows for dairy units that are generally in peri-urban zones (Sanogo, 2011). These specialised operations can be termed opportunist insofar as their economic success depends to a great extent on the market on which the livestock are purchased and then resold, dairy products are sold and inputs are also purchased—veterinary care and cattle feed.

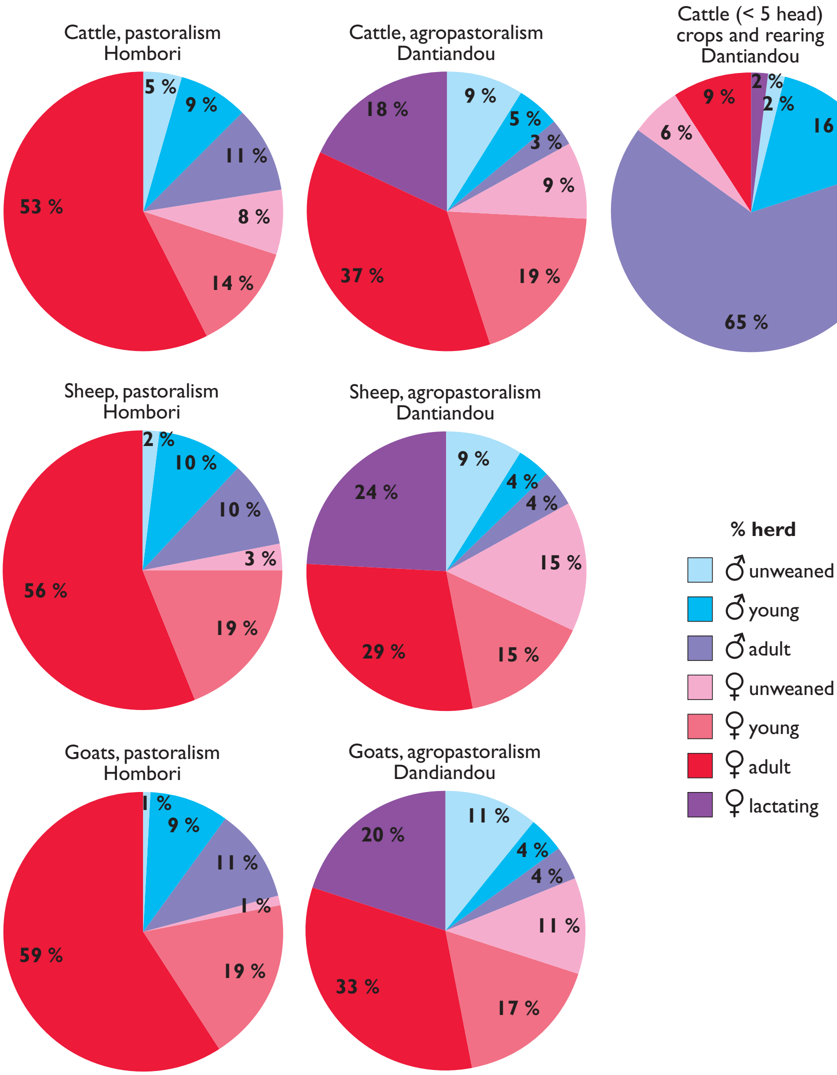

Figure 1.
Average composition by sex and age category of herds and flocks of graziers at Hombori, agropastoral farmers at Dantiandou, farmers and cattle rearers at Dantiandou (a single case of a herd of cattle of 5 animals or less). Livestock feeding young are shown as a separate category for Dantiandou.

More dependent on market conditions, they are also more intensive as they require greater financial investment, often in equipment (stable, store) and more labour (foddering and minding the cattle). Specialised rearing operations aim at production that sells better on the market and for which grazing alone may be insufficient, especially as these holdings are run by sedentary, sometimes peri-urban farmers with limited access to forage. The operations are therefore more rarely pastoral and when they remain so they are less dependent on grazing; a complementary energy, protein and mineral ration is added. This is in the form of cowpea or groundnut stalks, bran and cereal stubble and other crop or processing residues that are thus used, but taken from community pastoral resources. On small specialised operations, the complements are produced on-farm but they are also purchased on the market and affect the profitability of the business.

The great majority of Sahelian breeding and pastoral farms are closely dependent on the forage resources of rangeland for feeding their livestock. Specialised farms whose stock is supplied by breeding farms are less dependent on grazing but are in competition with breeding farms for cattle feed from rangeland. The rangeland forage balance thus concerns all categories of stock breeding either directly or indirectly.

Forage balances

A forage balance is drawn up using the difference between the forage available—more precisely the potential forage fraction of the plant material available and the forage requirements of livestock during the annual cycle. Common access to rangeland and the seasonal mobility of herds and flocks mean that these balances can only be drawn up for areas that are large enough to cover the major part of the movements of the resident stock; possible stays by herds from elsewhere must also be incorporated. The size of these areas and the large number and broad diversity of farmers and herds makes estimating forage availability and the requirements of livestock very laborious. Two case studies illustrate the approach: that of a pastoral breeding farm in the Gourma (Mali) and that of breeding farms and specialised agropastoral rearing operations in the Fakara (Niger). In the Gourma, the territorial unit was defined by a set of waterpoints in the community area of Hombori and its surroundings from which the livestock of people in the area and some belonging to farmers from elsewhere graze the land of the commune and that adjoining it (3,000 km^2). In the Fakara, the territorial unit is defined by the adjoining land of 12 villages and adjoining encampments, totalling 210 km^2 (of the total of 845 km^2 of the commune of Dantiandou).

Estimate of the forage resources of the land in the commune of Hombori and nearby areas

The commune de Hombori is at the northern limit of rainfed millet growing, with cultivated fields covering only a few percent of the landscape (Cheula, 2009) and making only a very secondary contribution to forage resources. The latter are provided mainly by rangeland but in very distinct proportions and quality for the three main components of the landscape: deep sandy soil forming about 77% of the land at Hombori (Nguyen C. C., unpublished data), shallow soil on erosion glacis and rocky outcrops (15%) and the loam soils and clayey soils of the valleys and plains (8%). The areas of these soil categories were mapped by supervision classification of high-resolution Landsat images. Indeed, the hydric properties of surfaces and soils in the three landscape components govern the surface redistribution of rain and its infiltration, governing structure and plant production. These are also influenced by differences in the biochemical fertility of soils (PENNING DE VRIES and DJITEYE, 1982). Average maximum herbaceous mass measured in September at 12 pastoral sites, including vegetation monitored since 1984 (MOUGIN *et al*., 2009), is set out for each year and type of substrate. The averages are weighted by the relative areas of substrates to assess the amount of herbaceous forage available at the end of the growth season (Fig. 2). Erosion glacis and rocky outcrops display available forage of from a few tens to several hundred kilograms dry matter per hectare whereas availability on clayey and loamy rangeland is from 500 to 1,500 kg and that on sandy rangeland is between 1,000 and 2,500 kg/ha. Weighted forage availability for all the Hombori rangeland could be doubled between 2008, a dry year, and 2011, a more rainy one (Fig. 2). However, only a fraction of the amount of forage available is used by livestock, first because of difficult access to part of the area and above all because of the distance from waterpoints during the dry season, and also because grazing causes losses by trampling and biotic degradation which, without counting possible fires, causes two-thirds of straw degradation during the dry season (HIERNAUX *et al*., 2012). Finally, it is estimated that useful grazing is a quarter of the total available.

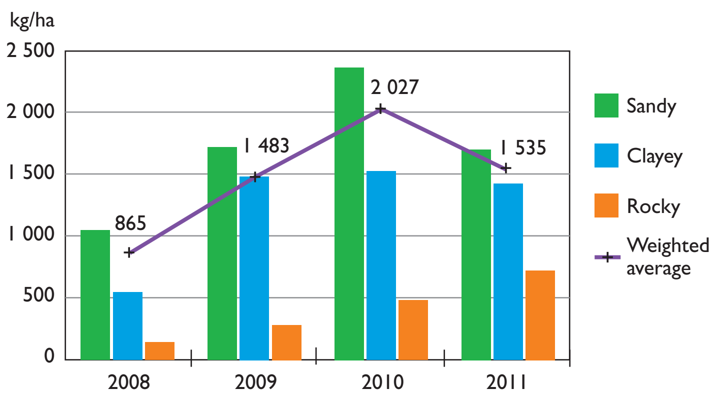

Figure 2.
Average by type of substrate weighted by the relative areas of substrates and of herbaceous masses at the end of the growth season in the commune of Hombori and adjoining areas. Measurements were made at 12 pastoral locations that are the subject of long-term monitoring (AMMA-CATCH network).

In Mamadou Diawara's thesis work, forage availability was also plotted spatially in the territory of the commune of Hombori to compare the evolution of forage in the areas served by waterpoints during the 2010-2011 dry season with the evolution of stocking levels by head counts at the waterpoints (Fig. 3). The map of available forage was plotted using a linear regression between the peak MODIS/Terra NDVI (index maximums for 16-day periods at 250 m resolution) during the rainy season and the herbaceous plant mass measured at 12 monitoring sites in and around the commune of Hombori: mass (kg ha^{-1}) = 9 979,4*NDVImax – 738.09 (r = 0.75, rmse = 12.5, n = 21) (Diawara, 2015)

The average available forage mass derived from this function for the territory of the commune was 1,844,9 ± 747.9 kg ha^{-1}. This estimate is a little lower than that based on averages (2,027 kg ha^{-1}), but spatialisation makes it possible to analyse the balance by the areas served by waterpoints.

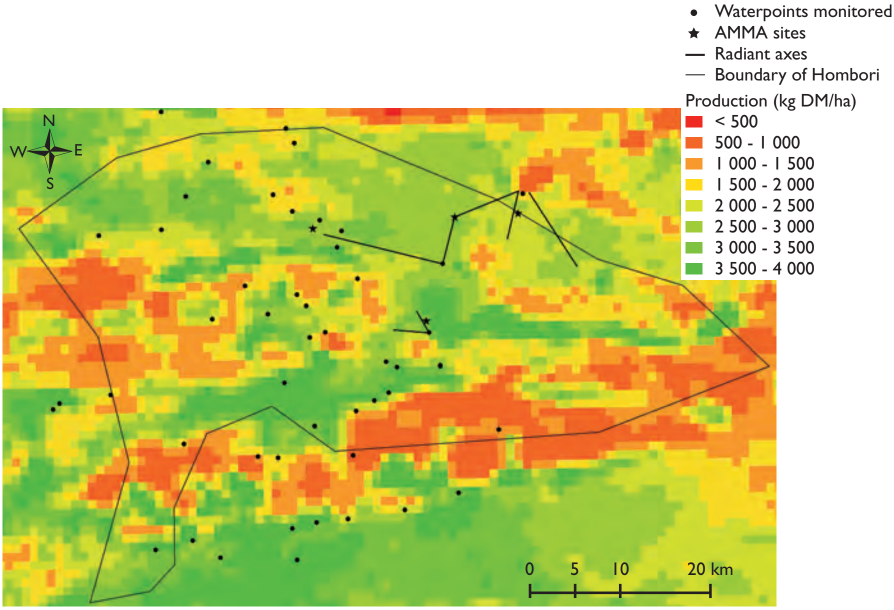

Figure 3.
Forage availability map for the commune of Hombori (Mali) at the end of the 2010 rainy season (kg DM/ha).
Source: Diawara (2015)

Estimate of available forage in the areas of 14 villages in the commune of Dantiandou

Millet fields cover a little less than half of the area of the commune of Dantiandou and make a considerable contribution to forage resources (Fig. 4a). Forage availability is therefore estimated using the areas of three types of land use in the pastoral zones of 14 villages in the commune with a cumulated area of 210 km^2 (of the 845 km^2 of the commune). The area is estimated from land use maps plotted each year from

2009 to 2011 by supervised classification of Spot multispectral images (Fig. 4a). Available forage mass was calculated for each of the three land use types by ground measurements at 24 sites (72 were monitored but destructive measurements were applied to a 24-site sub-sample). Only herbaceous plant organs with forage value were taken into account, that is to say herbaceous plants in rangeland or fallows, weeds and millet straw leaves in the fields (Fig. 4b). Land use types are not independent of topo-geomorphological positions: uncultivable rangeland is on indurated (hardpan in the intermediate area) and the bordering scarp but also the upper part of slopes where weathered and decayed Continental Terminal sandstone outcrops and on the hardpan soils at the base of the slope (piedmont hardpan). Millet fields and fallows are in the sandy soil found on a few fixed dunes above the plateau and above all on sandy deposits on valley slopes and on the alluvial deposits in valley bottoms. Sampling of sites was performed with care taken to show the diversity of these positions (HIERNAUX *et al.*, 2009 a).

Total herbaceous forage resources in the 210 km² of the 12 agropastoral areas were estimated at 13,597 t DM in 2009; the figure increased to 16 293 t in 2010 before falling to 13 401 t in 2011. A kind of compensation is seen in the fluctuations recorded for each type of land use. Only a fraction of the forage available is of practical use for livestock whose grazing is selective (AYANTUNDE *et al.*, 1999) and that avoids grazing certain species that are abundant unfortunately at Dantiandou (*Mitracarpus scaber* and *Sida cordifolia* are very common). Grazing causes losses by trampling and biotic degradation which, without counting possible fires, causes two-thirds of straw degradation during the dry season (HIERNAUX *et al.*, 2012). Finally, the useful fraction of grazing is estimated to be a quarter of the forage available, as at Hombori.

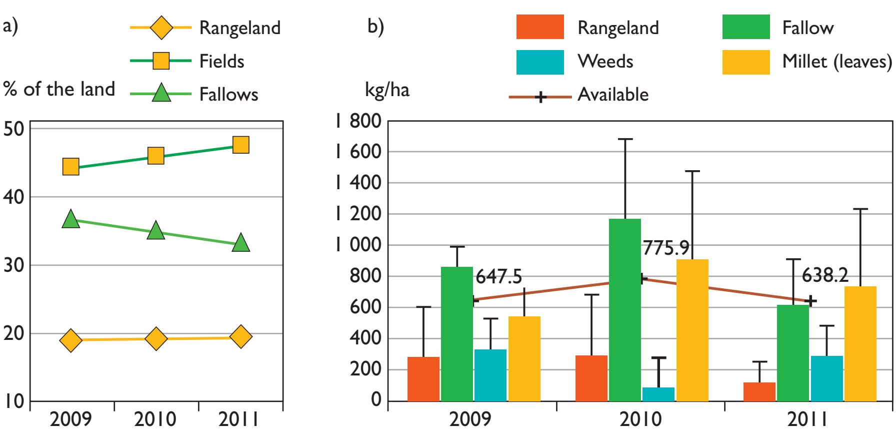

Figure 4.
a) Evolution of use for farming in the land (210 km²)
of 12 villages in the commune of Dantiandou, Niger, from 2009 to 2011.
b) Average annual forage by land use measured at 24 sites
where plant cover and average available forage are recorded (kg DM)/ha.

The forage balance in the commune of Hombori

Assuming that stocking varies little from one year to the next in both numbers and composition, forage requirements are calculated for the numbers counted from March 2010 to June 2011 taking into account the structure of stock by sex and age category (Table 1) and the evolution of average weights and forage digestibility over the seasons. Monthly livestock counts are performed at the main waterpoints in the commune—about 50 ponds, sumps, wells and tanks are grouped in 20 waterpoints (DIAWARA, 2010). This count underestimates stocking as it does not cover livestock that drinks in small, unlisted ponds during the rainy season. Stocking is calculated from the numbers observed from October to June in order to correct this under-estimate (Table 1).

The herbaceous forage intake of this stock is estimated from the average daily intake calculated for each animal category using an intake rate of 98 g per kilogram of metabolic weight (live weight to the power of 0.75). The fraction of ingested forage consisting of herbaceous forage is then deducted from total ingested forage, considering that the ration of cattle and donkeys is mainly herbaceous (95%), that of sheep 85% herbaceous and that of goats and that of camels 60% with the complement consisting of grazed foliage of ligneous plants.

The forage requirement of livestock on the Hombori rangeland is estimated to be 50,964 tonnes of herbaceous forage (average 170 kg/ha). Compared to the available herbaceous forage in the 3,000 km² of the commune and the surrounding area, this use is low, reaching 78.5% of the usable fraction in 2008, a drought year, and between 33 and 46% in the three following years (Fig. 5). These overall statistics would thus seem to show that there is not a forage problem at Hombori. However, the livestock feed situation was critical at the end of the 2008-2009 dry season, with exceptional migrations and the provision of supplementary feed. The apparent contradiction is explained on examination at a more local scale of the areas supplied by waterpoints. The straw and litter degradation model for the dry season according to livestock density using the resources working outwards from the water points (MOUGIN *et al.*,

Table 1.
Head of livestock counted once a month at drinking at some 20 waterpoints in the commune of Hombori.
Monitoring from March 2010 to June 2011.

	Males			Females				Average
Species	**unweaned**	**young**	**adult**	**unweaned**	**young**	**adult**	**Total head/year**	**October to June/year**
Cattle	13 494	24 529	32 657	23 309	40 477	150 925	285 393	337 741
Sheep	2 461	15 173	15 043	3 991	29 435	83 827,6	149 931	173 275
Goats	1 429	21 747	25 518	2 501	43 227	133 831	228 253	263 853
Donkeys	893	1 147	2 985	1 106	1 355	4 418	11 904	24 642
Dromadaries	25	120	458	36	112	572	1 323	1 320
Horses	11	39	67	30	39	141	327	340

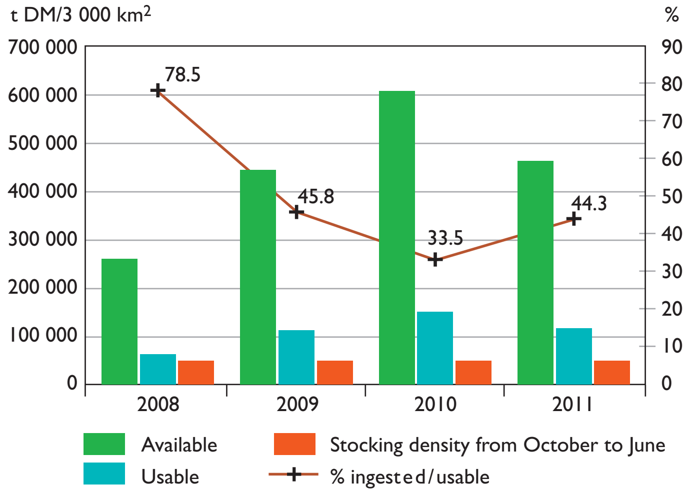

Figure 5.
Inter-annual variations of the annual herbaceous forage available, of the fraction that can be used by livestock, of the estimate of forage ingestion and of the ratio of ingestion to the usable forage in the territory of the commune of Hombori and the surrounding area from 2008 to 2011.

1995), calibrated using observations and measurements made in three waterpoint supply areas in the commune reveals very different rates of use of resources from one area to another (Fig. 6).

Two of the main waterpoints—perennial ponds with public access—reach the theoretical maximum of 33% while the rates of use of the resource are lower in the other areas with an overall average is 9.4%. It is therefore possible even in a fairly

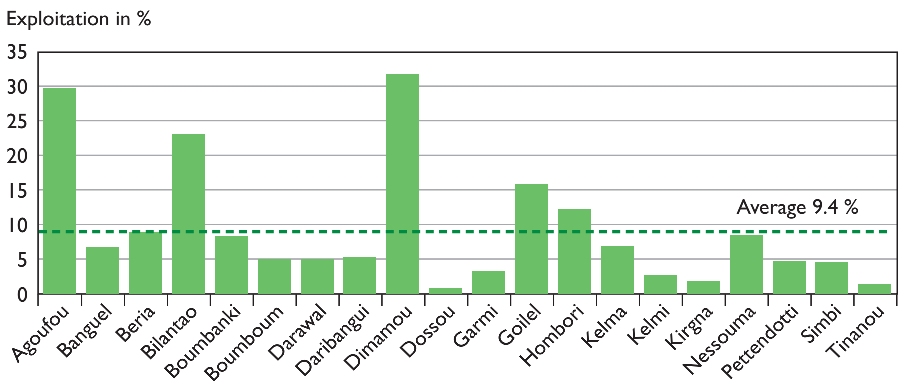

Figure 6.
Grazing intensity around pastoral waterpoints: rate of use of forage by livestock during the 2010-2011 dry season.
Source: Diawara (2015)

favourable year to observe livestock in a situation of seasonal under-nutrition (Fernàndez-Rivera *et al*., 2005). This contributes to poor reproductive performance and the high losses observed in the major droughts of 1972-1973 and 1983-1984 (Dawalak, 2009).

Forage balance at Dantiandou

An exhaustive survey of family livestock in 12 villages and associated encampments in 2010-2011 documents the livestock by species, sex and age category, with distinction made between unweaned young animals, weaned young animals, adults and lactating female adults (Table 2).

The ingestion of herbaceous forage by this livestock is estimated using average daily ingestion calculated on the same basis as for Hombori: ingestion of 98 g per kg metabolic weight. For this, a standard weight was used by category of age and sex for each species (Table 3), and the forage ingestion calculation was performed by sex and age category for each species.

As at Hombori, the herbaceous forage fraction of ingestion is deduced from forage ingestion using the same average forage selection coefficients. Annual forage ingestion by the livestock in the 12 areas is thus estimated to be 5,046 t DM, of which 4,521 t consists of herbaceous material, including millet straw (Table 4).

This total is only a fraction of the forage mass available (average 14,430 t from 2009 to 2011). However, it exceeds the proportion of available forage considered as being usable by the livestock (3,608 t) as a result of losses by trampling, herbivores and decomposition and also because of the large contribution of non-forage species (including *Mitracarpus scaber* that is dominant in fallows). The ratio of ingested forage to the usable quantity is thus always greater than 100% (Fig. 7), underlining the acuteness of the question of forage at Dantiandou.

Table 2.
Sedentary livestock in 12 villages and encampments in the commune of Dantiandou in 2011, by species, sex and age category.

		Males			Females				Total
Species	**Villages**	**unweaned**	**young**	**adults**	**unweaned**	**young**	**adults**	**lactating**	**head**
Cattle	Camp	165	91	60	167	318	621	315	1 737
	Village	56	97	231	39	81	190	94	788
	All	221	188	291	206	399	811	409	2 525
Sheep	Camp	180	83	65	282	262	547	447	1 866
	Village	113	37	12	101	74	199	199	735
	All	293	120	77	383	336	746	646	2 601
Goats	Camp	157	59	52	180	237	471	306	1 462
	Village	84	30	20	66	73	81	134	488
	All	241	89	72	246	310	552	440	1 950

Table 3.
Unit weight standards for livestock by species, sex and age category
and the corresponding average forage ingestion calculated using metabolic weight.

Sex	**Age category**	**Live weight (kg)**			**Daily forage ingestion (kg MS)**		
		Cattle	Sheep	Goats	Cattle	Sheep	Goats
Male	unweaned	50	7,5	6,25	1,843	0,444	0,387
	young	100	15	12,5	3,099	0,747	0,651
	adult	200	30	25	5,212	1,256	1,096
Female	unweaned	45	6,25	5	1,703	0,387	0,328
	young	90	12,5	10	2,864	0,651	0,551
	adult	180	25	20	4,816	1,096	0,927
	lactating	200	30	25	5,212	1,256	1,096

Table 4.
Estimated annual ingestion of forage by the resident livestock in 12 villages
and encampments of the commune of Dantiandou.
The proportion of herbaceous forage including millet straw is estimated separately.

	Annual forage ingestion in t MS in a area of 210 km²					
	Herbaceous and ligneous foliage			**Herbaceous only**		
Species	**Encampment**	**Village**	**Total**	**Enampment**	**Village**	**Total**
Cattle	2 455	1 208	3 663	2 332	1 148	3 480
Sheep	407	130	538	516	201	717
Goats	607	236	844	244	78	323
Total	**3 470**	**1 575**	**5 046**	**3 093**	**1 427**	**4 521**

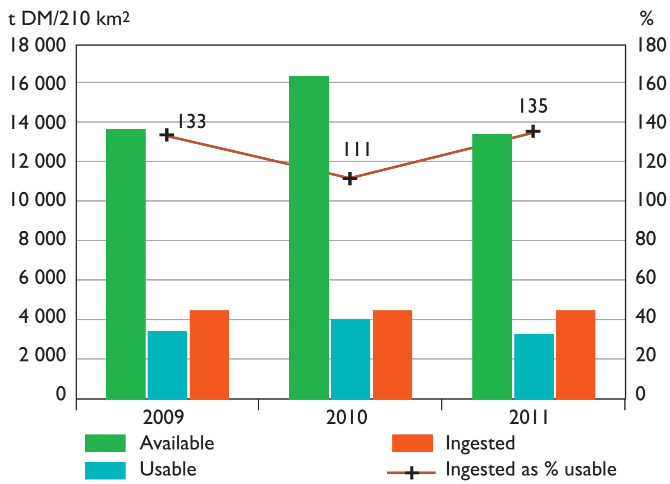

Figure 7.
Estimated annual forage availability with the usable proportion
and that ingested by livestock during an annual cycle (t dry matter) in the pastoral area
of 12 villages in the commune of Dantiandou (210 km²) from 2009 to 2011.
The curve of the ingested proportion of usable forage is shown in %.

Comparison of the forage balances drawn up for Hombori and Dantiandou

It might seem paradoxical that the forage question is more acute at Dantiandou where rainfall (565 ± 142 mm at Niamey during the period 1905-2012) is more abundant and regular than at Hombori (376 ± 107 mm during the period 1935-2012). However, available herbaceous forage per unit of surface area is less on average at Dantiandou, even if it is less variable from one year to the next (Figs. 2 and 4). The reason is mainly the fact that nearly half of the land is used for growing millet, whose only pastoral resource is leaf straw (the stems are not eaten, unlike those of sorghum) and weeds. It is also caused by poor herbaceous production on rangeland on the indurated plateaux and their borders subjected to very strong grazing pressure during the rainy season when livestock is kept out of crop fields (Turner *et al.*, 2005).

Furthermore, stocking over the year is slightly greater at Dantiandou with 8.4 TLU/km² (2,108 kg live weight per km²) exerting grazing pressure with forage consumption of 215 kg/ha whereas average stocking at Hombori is 7.0 TLU/km² (1,742 kg live weight per km²) and grazing pressure corresponds to average herbaceous forage consumption of 169 kg/ha. However, more detailed estimates at the scale of the areas served by waterpoints at Hombori show that this average figures hides very contrasted realities with consumption close to the maximums possible (a third) near the most frequent waterpoints while the standing forage reserves are little exploited when they are at some distance from the waterpoints. But this is part of the security margin used by certain livestock farmers during crisis situations (Benoit, 1984).

These forage balances are just a guide as the chronic forage shortage at Dantiandou renders the situation impossible without the adaptive practices of livestock farmers that are not included in these balances. For example, Dantiandou livestock farmers address the forage deficit by organising the seasonal migration out of the commune of part of the livestock. During the rainy season, livestock is driven to pastoral areas 300-400 km further north, near the frontier with Mali (Turner *et al.*, 2006). When they return at the time of the millet harvest, part of the herds are driven about 50 kilometres to the east in the neighbouring Dallol and, if necessary, some also go south at the end of the dry season (Brottem *et al.*, 2014). The other solution is to supplement pasture with feed given to livestock in enclosures and resting and milking sites (Ayantunde *et al.*, 2008). This feed is produced partly on the farm—millet bran, stems of cowpea, groundnut, Bambara groundnut and residues of roselle. Part of this is harvested in rangeland (*Zornia glochidiata* straw, millet straw, particularly appetible weeds such as *Alysicarpus ovalifolius*, *Eragrostis tremula*, *Jacquemontia tamnifolia* and acacia seed pods) and—more rarely—purchased on markets (bran, oilseed cake). It should be noted that the harvesting (or setting aside) of feed such as straw and stubble competes directly with grazing.

Forage balances and livestock productivity

Do the differences in forage balances between Hombori and Dantiandou result in a difference in livestock productivity? Surveys of livestock farmers were performed at the two sites, focusing on the size and composition of flocks and herds, demographic parameters (deaths, losses, sales, births, purchase and gifts) and the reproduction parameters of females (age at first birth, reproduction career, age at disposal). These data are used in Dynmod, a matrix model of the dynamics of livestock populations (LESNOFF, 2010) to make a projection of flock and herd dynamics and production with the hypothesis of the maintaining of the initial structure of the herd or flock (steady state option). A single type of livestock farming—pastoral— was considered at Hombori, whereas at Dantiandou distinction is made between livestock farming by Peul families living in encampments and where numbers are greater and who practice more regional transhumance and the Djerma agro-livestock farmers living in the villages (HIERNAUX and TURNER, 2002). And in the latter case, cattle operations with fewer than 5 head are excluded from the analysis as they do not qualify as breeding operators and the simulation is therefore not suitable for judging their performance.

Livestock numbers vary considerably (Table 5). They are higher in pastoral operations; then come crop and livestock operations and are limited to 5 small ruminants and 13 cattle in sedentary crop and livestock systems. Annual rates of disposal (sale/stock) are similar in the livestock systems and at the two sites: 10 to 13% for cattle and 30 to 33% for small ruminants. In contrast, the performances of livestock systems differ in their growth rate, with the best being those of the crop and pastoral systems at Dantiandou. Those of the Hombori pastoralists are very irregular and even negative for sheep and finally those of the sedentary crop and livestock farms of Dantiandou are very weak and close to the viability point (LESNOFF *et al.*, 2012), confirming the farm trajectories described by several crop and livestock farmers (BONNET and GUIBERT, 2014). Thus the forage advantage of Hombori livestock farming does not result in better performance. But management by agropastoralists, and especially the use of mobility, results in distinctly better performances than those of the crop and livestock farmers who live alongside them at Dantiandou. This finding calls into question the application of the concept of carrying capacity in the zoological sense as the viability of the livestock operation does not depend in a major manner at least on the rangeland used.

Furthermore, the agreement between measurements of plant production on the rangeland at the two sites and estimates by satellite remote sensing confirms the increase in plant production on the Gourma rangeland over the last three decades and its decrease in the Fakara (DARDEL *et al.*, 2014 a; see Chapter 6). But this does not indisputably support the concept of ecological carrying capacity. Indeed, the regreening of the Gourma is explained is explained to a considerable degree by more abundant rainfall since the major droughts of the 1970s and 1980s and by the

Table 5.
The results of the Dynmod model simulating the dynamics of livestock populations (Lesnoff, 2010) for cattle, sheep and goats in pastoral livestock operations in Hombori (Mali), and agropastoral and crop and livestock farms at Dantiandou (Niger).

Site and type of system	Species	Head of livestock ♀	♂	adults	Live weight kg	Growth rate %/year	Rate of sale or other %/year
Hombori	cattle	39	17	56	9 986	1.1	12.7
	sheep	27	9	36	936	- 8.9	32.3
	goats	40	14	54	1 221	5.9	33.3
Dantiandou agropastoral	cattle	11.5	3.3	14.8	2 702	5.1	13.8
	sheep	17.1	4.5	21.5	477	14.9	30.4
	goats	13.5	3.8	17.3	293	15	34.5
Dantiandou crops-livestock	cattle ≥ 5	8.2	4.8	13	2 580	0.2	10.9
	sheep	3.7	1.4	5.1	108	3	33.3
	goats	3.5	1.5	5	83	2.7	31.3

resilience of the vegetation in the sandy soils that are dominant in the landscape (Dardel *et al.*, 2014 b). In contrast, the deterioration of plant cover in shallow soils on erosion glacis and rocky outcrops should continue after the years of drought (Hiernaux *et al.*, 2009 b), causing a deep-seated change in the hydrologic system (Gardelle *et al.*, 2010; see Chapter 9). The apparent degradation of the Dantiandou agro-ecosystem may be partly a result of the impact on the vegetation index of the increase in areas under millet at the expense of fallow (Hiernaux *et al.*, 2015). The degradation of rangeland seen in the field would seem to have a negligible impact on the satellite index.

Conclusion: prospects for the development of livestock farming in the Sahel

Can Sahelian livestock systems adapt to the rapid development of the market for livestock products accompanying the demographic and urban growth of the sub-region and to the globalisation of trade (Zoundi and Hitimana, 2008)? With the exception of poultry, the response is often expected from special livestock operations—fattening units and dairy farms—that are frequently in peri-urban zones and with close links to markets (Williams *et al.*, 1999; Corniaux, 2005; Coulibaly, 2008; Sanogo, 2011). However, their productivity is restrained by access to high-quality forage and when they do not use grazing their viability depends on access to cattle feed and its cost.

Part of their economic viability is linked with purchases at low prices and on a steady base of young animals—especially males—produced by pastoral rearing operations. But pastoral breeding has only limited capacity for increasing the production of young livestock because of the forage constraint. Availability, related to climatic events, is still irregular. Both local and regional pastoral mobility is the major adaptation used by breeders to variations in forage availability, but the latter is increasingly limited because of the spread of crops and infrastructure, the increased scarcity of qualified labour, risks of landholding legislation favouring private ownership at the expense of community land (Lavigne-Delville, 1998; Oxby, 2011) and increased civil insecurity (Bonnet, 2013). It is therefore urgent for all the sectors of livestock farming for water resources and grazing land to be made secure and for suitable infrastructure for education, health and communications to be developed in pastoral regions (Plateforme pastorale tchadienne, 2013).

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Chapter 9

Paradoxical pond changes in the non-cultivated Sahel

Diagnosis, causes and consequences

Laurent Kergoat, Manuela Grippa, Pierre Hiernaux, Johanna Ramarohetra, Julie Gardelle, Cécile Dardel, Fabrice Gangneron, Laetitia Gal, Luc Descroix

Introduction

An unexpected effect of the multi-decadal drought that affected the Sahel from the 1970s onwards has been an increase in surface water flows that have caused various phenomena described collectively as the ‘Sahelian paradox’. This paradox, that can be summarised succinctly as ‘less rainfall but more water in rivers’, is described by Descroix *et al*. (see Chapter 7). Most of the observations of the paradox were made in a cultivated Sahelian environment and the phenomenon coincided with substantial changes in land use with the progressive use of land for crops and the development of short fallows instead of long ones. As a result, increased runoff has often been attributed to these changes in land use. Meanwhile, fieldwork has shown that runoff in cultivated fields is intrinsically smaller than in fallows and savannah. This is not coherent with an increase in runoff caused by crop farming. Several authors have therefore considered that surface crusting causes the increase in runoff. In this context, the study of flows in pastoral Sahel—the subject of this chapter—sheds new light on both the spatial extent of the Sahelian paradox and the mechanisms operating in these hydrologic changes together with the effects that they may have on farming systems and land use in a sylvopastoral environment.

'The rains decrease and the ponds rise': ponds in the Gourma (1950 to 2010)

The first spatial area affected by the Sahelian paradox in pastoral—as opposed at cultivated—Sahel was shown by GARDELLE *et al.* (2010) for the Gourma region in Mali. Basing their work on the systematic use of images from earth observation satellites, declassified spy satellite images and aerial photographs (Fig. 1), GARDELLE *et al.* (2010) showed the spectacular increase in ponds surface area since the 1950s, with an acceleration of the phenomenon in the 1990s. The initial aim was to determine to what degree the personal field observations by Pierre Hiernaux from 1984-2008, which indicated an increase in water surface areas and a transition from temporary to perennial status for the Agoufou pond, could be quantified and considered a general case in the Gourma. It was also particularly interesting to determine when these changes occurred. The methods and main results of this study are shown here.

The Gourma in Mali is literally the right bank of the River Niger, where the latter forms a meander and reaches its highest latitudes. The Gourma is mainly endorheic, that is to say that runoff produced during the monsoon does not reach the river but feeds ponds or lakes. Two types of pond are present, with different spectral signatures: cloudy water and clear water more or less covered by aquatic plants.

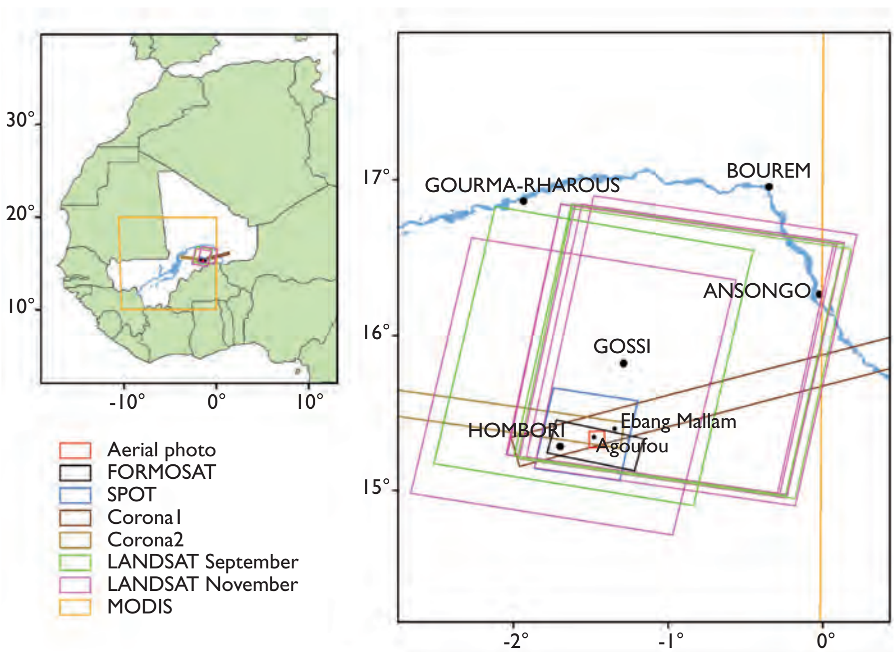

Figure 1.
Study site and footprint of the different images used by GARDELLE et al. *(2010) in the Gourma.*

Figure 2.
Example of ponds in the Gourma.
Top, 'Mare de Dimamou', water with low turbidity partially covered by aquatic plants.
Bottom, 'Mare de Zalam-Zalam', turbid water
and trees recently asphyxiated by an increasingly marked flood.

Two cases that are representative of the situation in the Gourma in Mali are a good illustration of the study by GARDELLE *et al*. (2010): the evolution of Agoufou and Ebang Mallam ponds near Hombori.

The example of Agoufou and Ebang Mallam ponds

The change is spectacular for these two ponds. The images in Figure 3 are at the same scale. At the Agoufou site, the small wooded depression in 1966 has become a pond or even a lake covering 300 ha during the rainy season. The *Anogessius* trees found in the small depression in 1966 have been asphyxiated by the rise in water level and are still present as dead trees in the middle of the pond.

More important perhaps than the increase in the surface area of a pond, increased runoff has resulted in the change from temporary to permanent pond. Figure 4 shows the full seasonal cycle of the Agoufou pond from 2000 to 2007. Even after

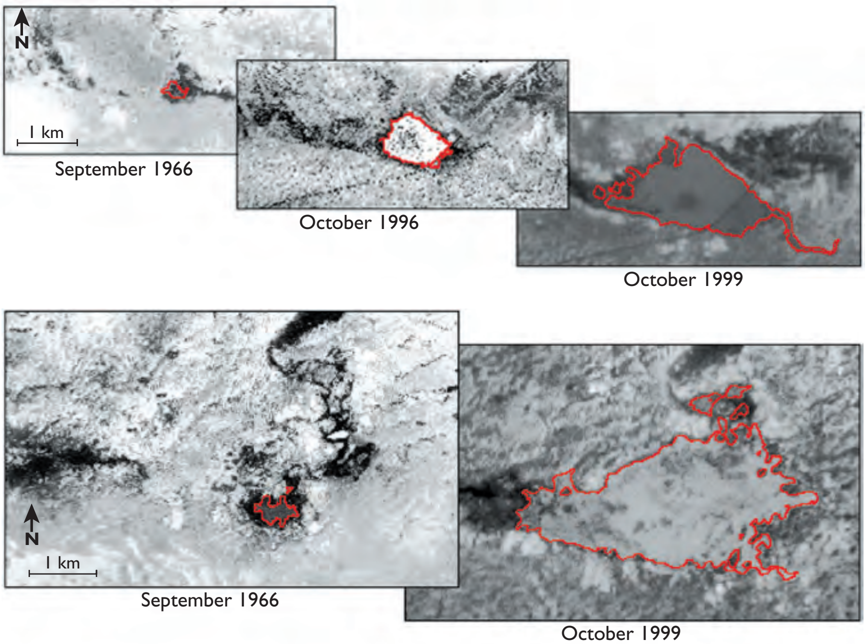

Figure 3.
Top, the evolution with time of the surface area of the Agoufou pond: 1966, in a wet decade, and then 1996 in a dry decade and 1999, a rainy year during the dry decades.
Bottom, the evolution of the Ebang Mallam pond.
The edges of the ponds are marked in red.
Source: from GARDELLE et al. *(2010).*

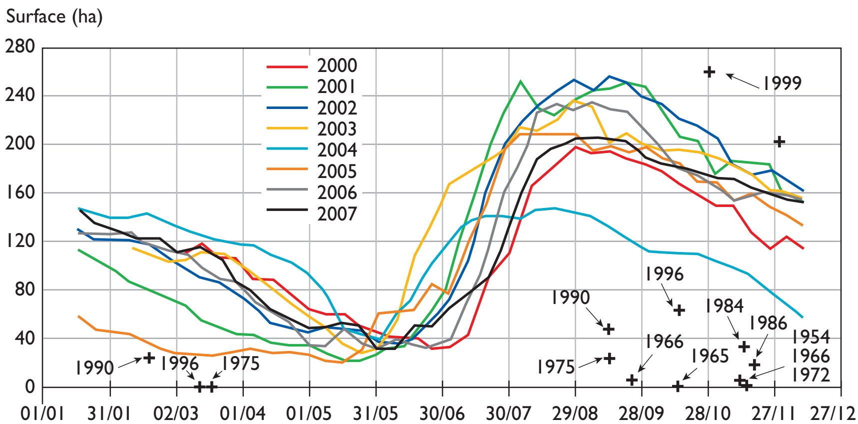

Figure 4.
The surface of the Agoufou pond at different dates shown in an annual cycle.
The present seasonal cycle can be seen clearly in the Modis data (in colour, from 2000 to 2007), together with all the very low pre-1984 August-November values.
These increase slightly in 1990 and 1996 before reaching the very high figures of 1999 and 2000-2007.

the driest years such as 2004, there was still water in the pond throughout the dry season. This was not the case before the 1990s. There is thus a new permanent waterpoint with important consequences for livestock and the population.

Looking at the whole Gourma

The same phenomenon was revealed by the systematic study of all the ponds and lakes in the central Gourma, delimited by the intersection of the Landsat data in Figure 1, which covers a zone of approximately 180 km by 100 km. The average surface area of the ponds has increased strongly (Fig. 5).

This spectacular trend is thus a general phenomenon. The behaviour of ponds displays some variability nonetheless. This results from the characteristics of drainage basins that may change with time and from the capture of one pond by another, especially in the case of a string of ponds. A broad distinction can be made between three geographic zones running from northern to southern Gourma. The increase in surface areas is more marked for the turbid water of northern and central Gourma, at latitudes from 15.5° to 17° N, where precipitations have totalled 150 to 350 mm per year in recent decades. This zoning might suggest a greater sensitivity of hydrologic systems in this precipitation range.

This first study thus shows in a spectacular manner that surface water has increased very strongly in the Gourma in the last 50 years. This dynamics started in 1984 and strengthed in the 1990s. The most noteworthy feature is of course that this evolution is not correlated with cumulated annual precipitation. This is illustrated for the Hombori meteorological station in Figure 6.

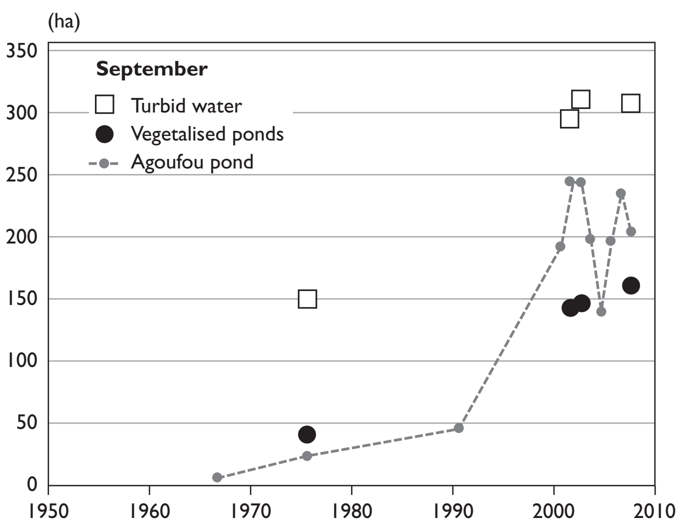

Figure 5.
Evolution of the average surface area of the 91 ponds in central Gourma in September.
Source: from Gardelle et al. *(2010)*

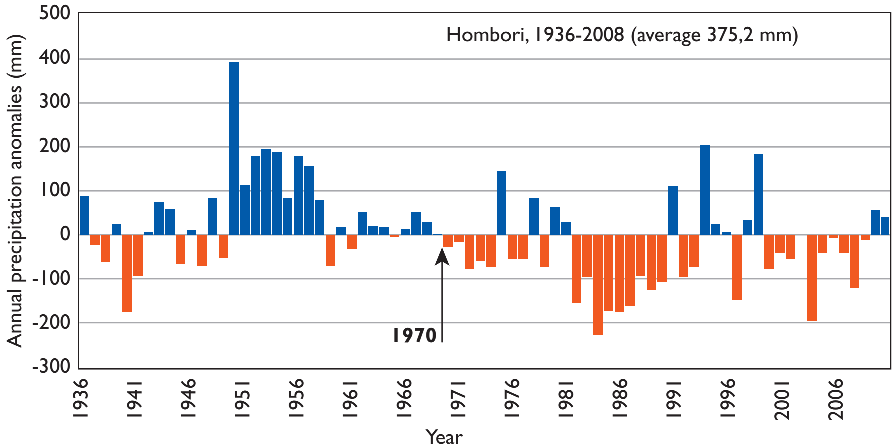

Figure 6.
Annual precipitation anomalies at Hombori (1936-2008), completed until 2011
(data from DNM, Mali).

Dividing the volume of water feeding the Agoufou pond by the precipitation volumes for the whole drainage basin gives the runoff coefficient, which displays a spectacular increase (Fig. 7).

In the Gourma as a whole, the surface areas of water increased after the major droughts of the 1970s and 1980s and then continued to increase during the next two decades (1990-2008, still a below-average period). GARDELLE *et al*. (2010) listed the factors that might have caused the phenomenon. They first rejected various potential causes such as engineering works, the clogging of ponds and changes in land use. Their analysis showed that the change in land use commonly put forward to explain the increase in runoff in the pastoral Sahel is not determinant either.

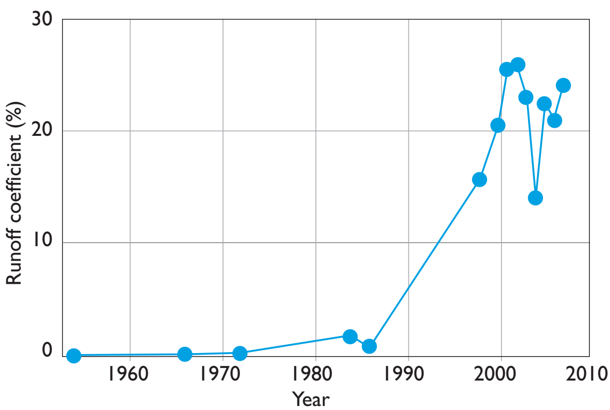

Figure 7.
Runoff coefficient in the Agoufou pond drainage basin.
Source: DARDEL et al. *(2014).*

Can an intensification of precipitation be excluded?

Rainfall regime intensification, which is observed at other latitudes and expected within the framework of climate change, was suggested by FRAPPART *et al*. (2009) for the Gourma and demonstrated by PANTHOU *et al*. (2014) for south-west Niger using daily precipitation data. Indeed, it might be expected that the greatest intensities cause more surface runoff for the same cumulated depth. It is difficult to exclude this factor but the trend detected by FRAPPART *et al*. (2009) and PANTHOU *et al*. (2014) mainly concerns 2000-2010. However, we have seen that the increase in the surface area of ponds started much earlier—in 1984 in fact— and took place above all in the 1990s, when no intensification signal was detected.

The most probable hypothesis selected for uncultivated Sahel area like the Gourma is that of a delayed effect of extreme droughts through eco-hydrologic changes, that is to say the system linking plant cover and the water cycle.

The Tin Adjar drainage basin (Mali)

Documentation of past pluridecadal periods—typically since the 1950s in this case—is rare and fragmented. However, Dubreuil and his colleagues at Orstom studied a small drainage basin in the Gourma at that time (DUBREUIL, 1972), namely the Tin Adjar basin in the northern part of the Gourma.

We visited this site again, during several field trips, and we also examined various remote sensing documents to see what changes had affected the basin from 1950 (a wet period) to today (dry periods or end of dry period).

The Tin Adjar basin covers about 29 km^2 and lies between latitudes 16.28 and 16.33 N at longitude – 1.65 W. It slopes from east to west but is almost completely closed by a quartzite barrier in the west that allows the wadi to flow via a well-defined sill, and by fixed dunes in the north and the south. Cumulated annual precipitation varies between 200 and 120 mm, depending on whether the decade is dry or rainy.

Mapping of the hydrological network using aerial images and high-resolution satellite images (KERGOAT *et al*. in preparation), shows that there was spectacular evolution from 1954 and 2007 (Fig. 8).

The most marked changes are increasing gullying, the development of a higher order network, the drainage of most mid-slope depressions and the extension of flood plains. All these features point to an increased runoff, despite cumulated rainfall was distinctly greater in 1954 and throughout the 1950s than in 2007 and in all recent decades.

The statistics calculated for the whole basin for surface types and their transitions between 1954 and 2007 reveal the main changes that took place between these two dates (Table 1).

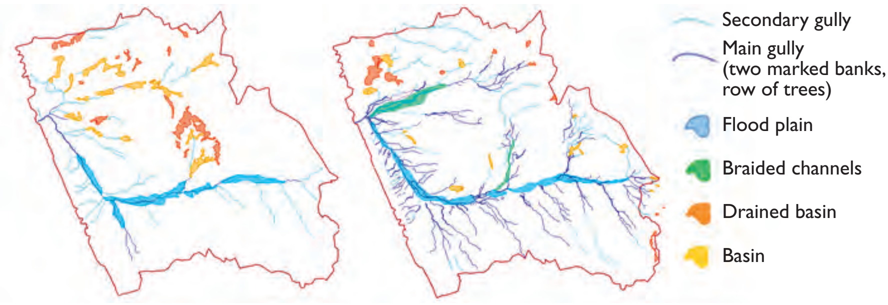

Figure 8.
Evolution of the hydrologic network of the Tin Adjar drainage basin between 1954 (left) and 2007 (right).
Source: KERGOAT *et al.* (in preparation.).

Tableau 1.
Relative area (in %) of the different types of surface at Tin Adjar (Mali) in 1954 and 2007.

Type of surface	**1954**	**2007**
Sand	40.4	29.4
Rocky outcrops and hardpan	31.9	43.2
Silt	13.3	20.0
Clayey-loamy depression	10.8	5.4
Tree cover	3.7	2.0

The most marked changes, shown in Table 1, are the increase in 'Rocky outcrops and hardpan' whose share increased by 12% of basin area from 1954 to 2007, the decrease in 'Sand' and the overall decrease of 'Clayey-loamy depression' and 'Tree cover'. The area of eroded loam also increased significantly. Taken as a whole, these figures indicate strong erosion in the basin.

The transitions also provide information (Table 2).

Tableau 2.
Matrix of the transition between classifications from 1954 and 2007.
Particularly noteworthy figures are in bold.

	Sand in 2007	**Outcrops**	**Silt**	**Clayey-loamy**	**Trees**
Sand in 1954	17.1	**12.4**	7.9	1.9	1.0
Outcrops	4.9	21.2	3.6	1.7	0.4
Silt	4.2	2.9	5.3	0.5	0.3
Clayey-loamy	2.3	**5.0**	**2.3**	0.9	0.2
Trees	0.8	1.6	0.8	0.4	0.1

The first interesting figure is that for ‘Sand’ in 1954 becaming ‘Outcrops’ in 2007. This figure indicates serious erosion on even gentle slopes of the drainage basin. Other categories make a small contribution to increasing outcrops also. Examination of the maps and Table 2 also shows that the lower part of the basin, near the outlet, shows signs of eroded and sand deposition. The second noteworthy point in the table is the almost total disappearance of clayey-silty depression, now replaced by outcrops, stripped loam or sand.

The next figure (Fig. 9) shows two zooms of a small part of the drainage basin close to the outel. Two rocky outcrop zones (in brown and black) can be seen in the 2007 image; the largest of these zones did not exist in 1954. Conversely, numerous areas of wooded low land present in 1954 (dark zones dotted with trees) have disappeared in 2007 and are replaced by areas of eroded silt layers, devoid of any vegetation. This silt layer—possibly a peri-desert loess—is a typical soil in the Gourma (DE GIRONCOURT, 1912). The development of the drainage pattern, which was limited in 1954, can also be seen in the northern part of the image. This part of the basin suffered considerable erosion, followed by alluvial deposits downstream, visible as pale pink sand in the 2007 image.

The changes in types of surfaces and the transitions between these types thus indicate a strong erosion of the whole catchment and considerable modifications of ecosystems. Indeed, sandy soil is favourable to annual herbaceous plants growth, accompanied by a few scattered trees; most of the trees are (or were) in clayey-loamy lowlands where dense herbaceous vegetation was also found, whereas no vegetation is possible on eroded silt, in current rainfall regimes at least. The concentration of runoff in a network of marked ravines is also unfavourable to the conservation of substantial plant cover because vegetation is deprived of the needed water. All these indicators strongly suggest that the increase in runoff results from the regression of plant cover, the concentration of runoff and erosion that caused rocky outcrops or areas of eroded silt that are not propitious for plant growth.

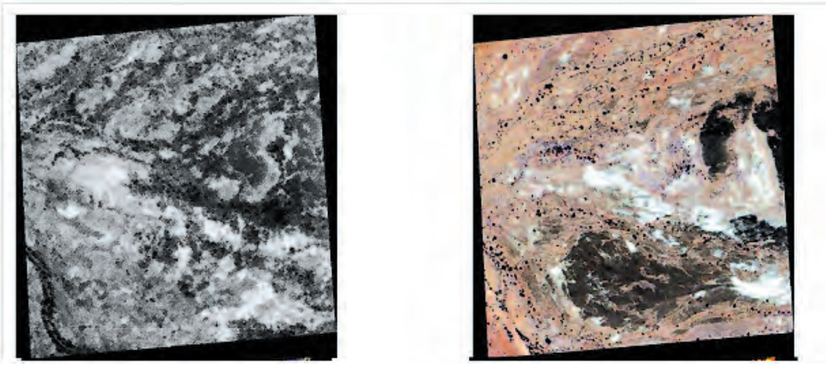

Figure 9.
Zooms of the Tin Adjar basin just upstream of the outlet.
Left, the 1954 aerial photograph.
Right, the 2007 Quickbird image.

A regional phenomenon?

In parallel with the research at Tin Adjar, we carried out work in the Hodh zone in Mauritania and in a mostly pastoral zone in Niger (Fig. 10) to study the 'Sahelian pond' phenomenon at a regional scale.

Using methods similar to that developed by GARDELLE *et al*. (2010), Calas & coll. (CALAS, 2012) also showed an increase in the surface area of ponds in the Hodh region in Mauritania Fig. 11).

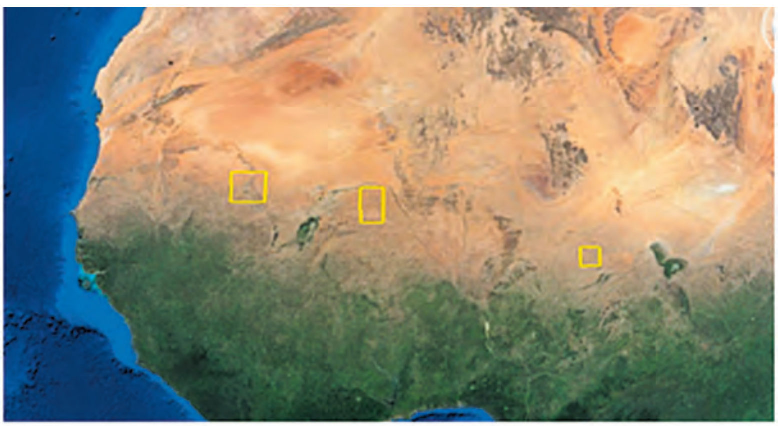

Figure 10.
Sahelian pond study zones from west to east:
Hodh in Mauritania the Gourma in Mali, the Zinder region.

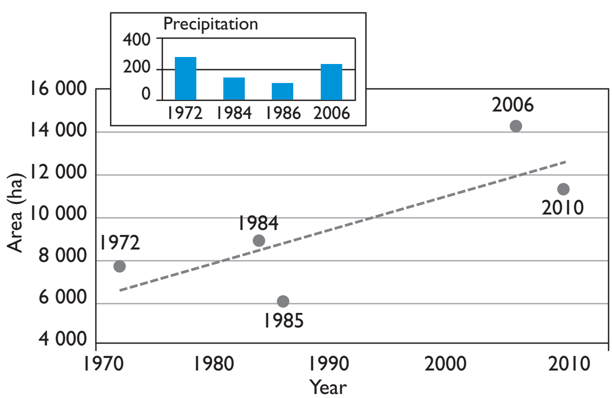

Figure 11.
Evolution of the surface area of ponds in the Hodh region, Mauritania, using a series of November Landsat images.
Source: CALAS (2012).

Precipitations were greater in the Hodh in 1972 (Fig. 11), which also suggest that there has been a change in the runoff coefficient, the water regime and ecohydrology in the region. Preliminary result show thatchanges in pond surface areas have also been detected in the Zinder region of Niger.

It can thus be seen that the increase in pond surface areas in the Sahel I observed from Mauritania to Niger in regions that share common features: 1) the ponds are fed mainly by runoff on shallow soils that do not necessarily cover a relatively large area but where runoff is very strong; 2) agricultural use of this land is very limited and local.

Possible mechanisms

Changing ecohydrology

We have seen that the ponds in several areas of the pastoral—uncultivated—Sahel in Mauritania, Mali and Niger have displayed a sometimes spectacular increase in surface area while precipitation has followed the opposite trend. This obviously raises the question of the mechanisms that cause this apparently paradoxical evolution.

It has been shown that the Sahelian paradox operates in uncultivated areas, meaning that there is at least one driver which is unrelated to crop farming. As the possible increase in precipitation has been ruled out, the most probable hypothesis is related to a change in surface runoff caused by a change in ecohydrology over shallow soils. It has been seen at Tin Adjar and also in other parts of the Gourma and south-west Niger that two changes operate in parallel: 1) a visible regression of the woody vegetation and also of the herbaceous cover, and 2) the development of concentrated runoff. Considerable erosion is sometimes added to this.

We therefore propose the following mechanism: the herbaceous vegetation consisting mainly of annual plants does not grow during an extreme drought. Rainy season runoff accelerates. Runoff is generally greater at the beginning of the rainy season before the growth of herbaceous plants (DUBREUIL, 1972). It can be hypothetized that runoff remains substantial throughout the season during drought years, even if the number of rainstorms is less that normal. This prolonged, accelerated runoff starts to take preferential paths, departing from ‘sheet runoff’ that usually prevails on these gently sloping shallow soils. The concentration of water further reduces the uptake of moisture by the vegetation since newly created gullies avoid the sandy sheets where herbaceous plants grow. These preferential routes are taken again in the following season, depriving vegetation of part of its moisture supply, which boosts the ecohydrological changes. This is a positive retroaction that can lead to serious water erosion in the most seriously affected areas like Tin Adjar.

Once the hypothesis of a degradation of plant cover in the Sahel has been put forward, it is immediately confronted to the general regreening observed from space, and also at ground level, described in detail in the chapter by Dardel *et al.* in this book.

Are degradation and regreening compatible?

The increase of the runoff coefficient is considered a desertification indicator. The present chapter and that by Descroix *et al*. (see Chapter 7) thus suggest that desertification, might be widespread in the Sahel. Plant productivity decrease is also considered a desertification indicator, for instance when there is a decrease in vegetation capacity to use precipitation. Field observations and satellite analyses of herbaceous production (Dardel *et al*. 2014) have shown that rain use efficiency (RUE), (sometimes put in the form of the residuals of the production:precipitation correlation as in Figure 12), did not change in the Gourma during the 1984-2010 period. This period starts at the peak of the drought and precipitation and productivity increased in parallel. Nevertheless, when focus is put on shallows soils only, which are not dominant in this region, a decrease in RUE and in the residuals of the linear production:precipitation relation are observed.

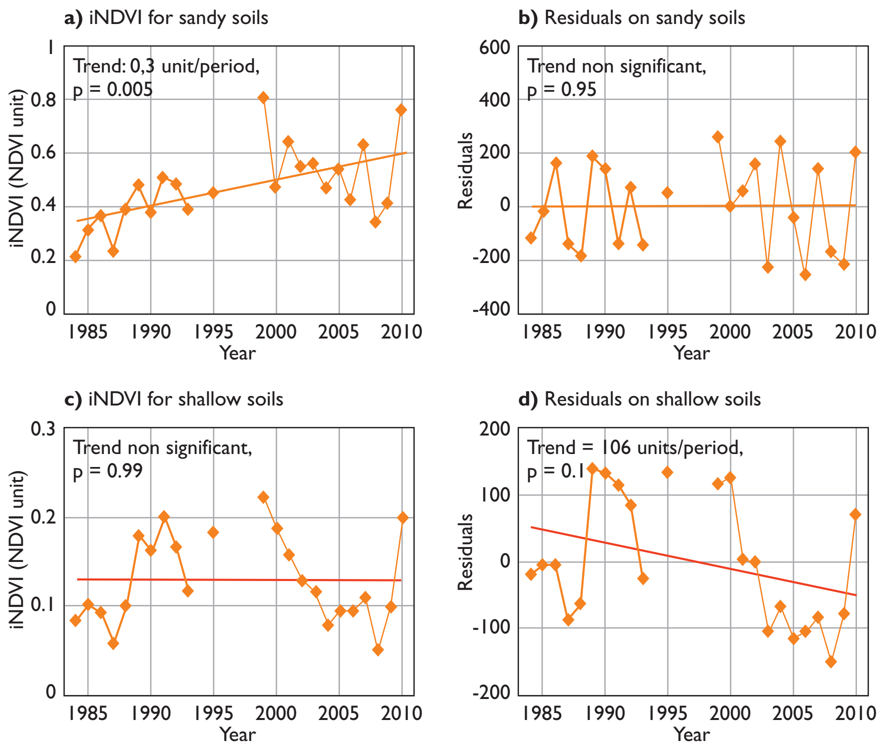

Figure 12.
Evolution of the vegetation index over sandy soils (a) and shallow soils (c) during 1984-2010. The part of the signal not explained by precipitations (residuals of the NDVI/precipitation) is figured on the right (d).
A stable signal(b) shows that the ecosystems on sandy soils are resilient whereas a decreasing trend (d) implies degradationfor shallows soils (d).
Source: Dardel et al. (2014).

Overall Sahel regreening and vegetation degradation over small areas can therefore occur during the same period, with the second phenomenon occupying little space and being masked by the general resilience of ecosystems, clearly dominant in terms of surface area.

Consequences of this environmental change

The evolution of water bodies following the most severe droughts of the 1970s and 1980s impacts several aspects of the farming and livestock production systems and more widely on rural societies and ecosystems in the Sahel. For example, geology in the Gourma results in ground water being scarce, little usable and little used. In contrast, surface water is available everywhere during the rainy season and then decreases strongly during the dry season, leaving just a few permanent ponds in March-April-May. In very schematic terms, permanent water bodies and the rare deep wells allow the installation of villages whereas temporary ponds allow temporary occupation of a territory, particularly to pastoralism. The case of the Agoufou pond is a good illustration of the development of a village and also of an important area for livestock during the dry season. New permanent ponds give opportunities to settle for people commonly exposed to an extrem scarcity of water resources. Indeed, during the dry season, only areas close to permanent waterpoints are occupied for long periods in the Gourma. The impact of the observed ecohydrological changes in the Sahel is therefore not a simple question. It rapidly interferes with questions of occupation of territories by livestock and people and with the social aspects of access to water and land resources.

Conclusions

The phenomenon of increasing surface water caused by the ecohydrological response of shallow soils to extreme droughts (1973, 1984) can be seen as ‘degradation’ in terms of a decrease in plant productivity that is difficult to reverse in the short term. Nevertheless, the concentration of rainwater in ponds prolongs water availability in the dry season. This has substantial and often considerably positive impacts on several types of activity and also ecological consequences, especially for the fauna, like, for example, the emblematic elephants that spend the dry season in the Gourma and visits the permanent ponds.

The question of the sustainability of this phenomenon has to be raised. To reverse the concentration and increase of runoff, it would be necessary to either fill the gullies, which is difficult to conceive physically, or to have fairly large regular precipitations. Vegetation could then grow on the sandy deposits and loamy bars and stop the acceleration and concentration of surface runoff. Furthermore, in eroded areas such as Tin Adjar, prior sand deposition over rocky outcrops (by wind) would be necessary. It is difficult to know whether such conditions can prevail in the forthcoming decades. It is reasonable to consider that the concentration of runoff and the filling of ponds will continue in the forthcoming decades rather independently of the amount of precipitation. However, it is essential to have models that represent this Sahelian paradox as soon as surface water resources are important in order to avoid erroneous simulations of the future water resource for these zones.

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Chapter 10

The impacts of climate change on crop yields in West Africa

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Introduction

Climate has a very strong influence on farming, which is considered to be the human activity that is most dependent on climate variations (Oram, 1989; Hansen, 2002). The impacts of climate on agriculture vary from one part of the world to another, with particularly marked socioeconomic consequences in developing countries in the tropics. Indeed, these countries experience great climatic variability, such as the monsoon regime in India and West Africa and the influence on the American continent of El Niño events (Challinor *et al*., 2003). In many cases endemic poverty increases the risk and seriousness of natural catastrophes (UNPD, 2004).

The rural populations of sub-Saharan Africa are particularly exposed to climatic events as they are closely dependent on rainfed agriculture, practiced on nearly 93% of cultivated land. It is reminded that 80% of the cereals eaten in sub-Saharan Africa are produced by this traditional farming and that the farming sector employs 70% of the total force (FAO, 2003) and forms 15 to 20% of GDP. In addition to this dependence, the rapid growth of the population and its poverty prevents access to technological adaptation (mechanisation, fertilisers, irrigation) and are factors that aggravate the socioeconomic effects of the climate (UNDP, 2004). Indeed, the limited means of rainfed agriculture for anticipating and correcting the effects of climate fluctuations is illustrated clearly by the strong correlation between agricultural productivity and rainfall, with consequences for food security. Since the 1970s, the most serious famines that required international food aid (1974, 1984-1985, 1992 and 2002) were caused entirely or partly by climate variations (Dilley *et al*., 2005).

This being so, *being able have better understanding and anticipation of climate fluctuations and their consequences for agriculture* is a major issue for development and food security in sub-Saharan Africa.

If sub-Saharan Africa frequently faces food insecurity today, what is going to happen in the future? A retrospective look at the movement in recent years gives a fairly pessimistic view of the future. Indeed, in spite of an increase in food production, very strong population growth has caused an increase in the poverty rate and malnutrition in Africa that is faster than anywhere else in the world, with a lower index of agricultural production per person than in other continents. According to COLLOMB (1999), taking into account requirement projections for 2050, when the United Nations considers that the world population will peak, extremely great efforts must be made to increase food production: that in Africa should increase more than fivefold between 2000 and 2050! The future of this region thus depends on the ability of the farming sector to meet the challenge of feeding a rapidly growing population. Succeeding this will be all the more difficult as climate change is now an ongoing phenomenon and will certainly have consequences for agriculture in Africa as elsewhere. The fourth and fifth Assessment Reports (AR4 and AR5) of the IPCC (Intergovernmental Panel on Climate Change) published in 2007 and 2014 respectively, have alerted the international community about an increase in temperature everywhere in the world and a probably increase in the frequency and intensity of major meteorological events such as droughts, with Africa mentioned as being the continent most vulnerable to changes in climate (IPCC, 2014). There is no doubt that a change in rainfall intensity and/or regime will affect the crop farming and pastoral systems in sub-Saharan Africa (CGIAR, 2009). Irrigated farming, like rice growing which plays an important role in feeding the urban population in Africa, will also be affected—not only because of a possible change in the availability of water but because of the rise in temperature that can lead to substantial decreases in yields (DINGKUHN, 1995; DINGKUHN and MIEZAN, 1995; DINGKUHN *et al*., 1995). It therefore seems crucial to be able *to provide a more accurate image of the expected evolution of agricultural production potential in sub-Saharan Africa in the context of warming of the climate.* However, the task is still difficult because of the strong uncertainty in regional climate change projections, in the response of plants to environmental changes (rainfall, temperature, atmospheric CO_2 concentration), in the linking of agronomic and climatic models and in the way farming systems will adapt gradually to environmental changes (CHALLINOR *et al*., 2007). The aim here is 1) to draw up an objective appraisal of the literature on the effects of climate change on agriculture in West African and 2) to understand the determinants of this response.

Drafting future yield scenarios

The literature on the impacts of climate change on agriculture in Africa and elsewhere in the world displays characteristic methodology described in Figure 1.

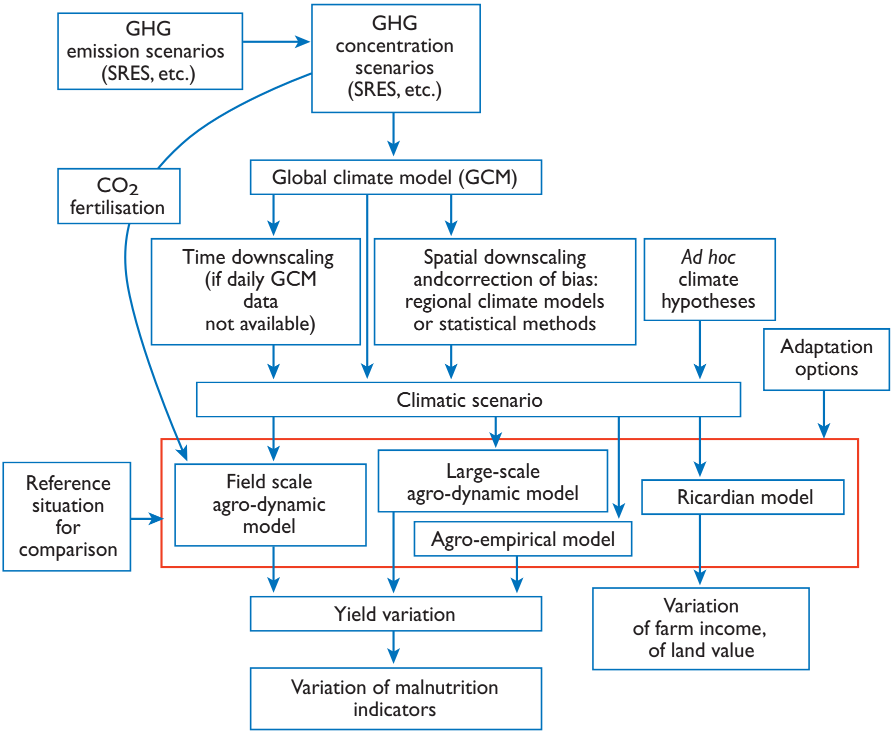

Figure 1.
Summary of the working method used in studies of impacts of climate change on yields.
Source: from Roudier (2012).

Thus, the following main stages are required in quantification of the variations in crop yields resulting from climate change.

Generating the future climate

Quantifying the impact of climate change on a given variable first requires the definition of the scenarios that describe the future evolution of the meteorological variables. The simplest method is to create a uniform scenario (e.g. + 10% rainfall, + 2°C in temperature) and to apply the change to observed climate data for the reference period (Ben Mohamed *et al.*, 2002; Salack, 2006; Vanduivenbooden *et al.*, 2002). However, it is clear that although the method makes it possible to perform analyses whose sensitivity is interesting it is based on strong hypotheses as regards the future climate and does not necessarily maintain the coherence between climatic variables. An approach with more solid scientific bases exists, with the use of global climate models (GCM). As has been seen in Chapter 3, GCMs give a great variety of responses depending on the emission scenario or model used. Thus, in order to sample part of the uncertainty of climate projections, most of the studies published use several GCMs and/or scenarios (e.g. Schlenker and Lobell, 2010).

Crop modelling

Constructing a model in which climatic information (temperature and/or precipitation for example) can be transcribed as agronomic variables (crop yields, biomass) is a prerequisite for the quantification of the links between climate and agriculture. This type of model is particularly useful for making a synthesis of existing knowledge on climate: plant relations, exploring hypotheses concerning climate change or farming practices, identifying key variables that should be pinpointed by researchers and drawing up scenarios for the future. Two separate approaches are generally used: the first is based on agronomic statistical models and the second on mechanistic models and both seek to estimate agricultural productivity in response to the climate. Empirical agricultural models are based on a statistical relation derived from observed data and that link agricultural yields at a given location with climatic variables. Although such relations are comparatively easy to set up, calibrating and validating a robust statistical model requires long data series (climate and yields). However, the relation has a particular advantage as it can be established directly at a large scale (national for example) using spatially aggregated climate data to predict yields in vast regions. The approach was used in particular by LOBELL *et al.* (2008) and by SCHLENKER and LOBELL (2010) who consider that it permits a simple evaluation of future climate impacts at a scale that is pertinent for informing decision makers.

The other approach is 'mechanistic' or 'dynamic' modelling based on equations representing the physiological processes of crop growth (uptake of carbon and nutrients, transpiration, etc.) and their development in response to the climate (e.g. the appearance of successive organs, vegetative phase, reproductive phase, etc.). As this approach can theoretically identify the intra-seasonal non-linear effects of climate on crops, most impact studies in agriculture use a mechanistic model (ROUDIER *et al.*, 2011). However, not all the models of this kind have the same physiological approach and do not attain the same degree of detail. In particular, the positive effect of a high atmospheric CO_2 concentration on photosynthesis (TUBIELLO *et al.*, 2007 a and 2007 b) is not taken into account in all mechanistic models (e.g. SALACK, 2006). Furthermore, these models require numerous parameters and are therefore used at field scale where these data are available and can be considered as homogeneous: they do not provide direct information on climate impacts at a larger scale.

It should be noted that a third approach, Ricardian analysis (MENDELSOHN *et al.*, 1994), is also used in estimating the impact of climate change on agriculture in West Africa (e.g. KURUKULASURIYA and MENDELSOHN, 2008; MOLUA, 2009). This approach is concentrated on the net income of farms rather than on yields and, unlike most impact studies, takes adaptation strategies into account. The Ricardian approach consists overall of several main stages: 1) the gathering of socioeconomic information about farms, 2) calculation of net farm return using this information, 3) establishing a regression between the calculated net return and different variables such as climate, soil and a set of economic variables, and 4) use of the link established between return and climate to project the impact of the future climate. It is noted that unlike empirical approaches, the regressions performed here are just for one year and so the method is a study of spatial variability.

Linking GCMs and cropping models

Combining a GCM and an agricultural model raises several problems. First, GCMs generally display significant bias in their climate simulations and especially in cumulated precipitation and regional distribution. The proportion of small rainfall events (< 10 mm/day) in cumulated total and frequency are over-estimated whereas the opposite occurs (under-estimation) for heavy rainfall (> 20 mm/day) (RANDALL *et al*., 2007; DAI, 2006). Thus certain impact studies that give local results generally require a certain correction of bias. The most simple correction method is the anomaly method. For a given GCM, an average annual anomaly calculated between the future and the current simulated climate is added to a current observed dataset (see for example MÜLLER *et al*., 2010). Secondly, the combining of a GCM and a deterministic model is more complex than the simple coupling of two models, because of the difference in the respective scales. Indeed, GCMs typically produce climatic projects for meshes with 2° side and although statistical models can be calibrated directly to use aggregated information of this type directly as input, mechanistic models require data at a finer scale. Downscaling must generally be performed from the overall GCM scale to the local scale of the agronomic model

Two types of downscaling are usually defined (and may sometimes be combined):

− statistical downscaling, in which empirical relations between atmospheric circulation at the meso-scale and the local climate are used to create realistic time series of local climatic variables. This method includes stochastic time generators, regressions (linear or not) and the weather type method. For example, ZORITA and VON STORCH (1999), MÜLLER *et al*. (2010) use a stochastic time generator to switch from monthly climatic variables to an hourly time step;

− dynamical downscaling uses models of the regional climate at a fine resolution (approximately 10-50 km) imbricated in the GCM (PAETH *et al*., 2011).

The need for agronomic modelling for studies on climate change has led recently to the development of mechanistic models at a global scale. These models are created and calibrated to function directly at a scale compatible with GCM output, making it possible to avoid the downscaling stage. Certain models have been developed to be independent of impact models while others are parts of models of overall vegetation where they are used for cultivated land (DE NOBLET-DUCOUDRÉ *et al*., 2004; BONDEAU *et al*., 2007; BERG *et al*., 2011). If necessary, they can thus be used for climate impact research.

Adaptation to climate change

Some studies on the impacts of climatic change take into account the adaptation of farming systems or populations. CHUKU and OKOYE (2009) held that there are four main categories of available options for adaptation in agriculture to face climate change: 1) income and asset management strategies, 2) government programmes and support 3) farm production practices and 4) technological developments. It is stressed in the same study that these categories are characterised by the scale (local, national) and the type of agents involved. Sahelian farmers already use numerous options for adaptation at the local scale. They generally involve production practices (e.g. water management, the use of certain varieties, fertilisation) and also income management techniques (e.g. the diversification of returns, migration). It is thus seen that it may be necessary to consider adaptation in this type of study in order to avoid over-estimating the impact of climate change on farm yields. However, adaptation is not taken into account explicitly in most studies on West Africa. In some studies, such as that of MÜLLER *et al.* (2010), sowing dates change each year but remain based overall on the same technique. This attitude is therefore more an adaptation to inter-annual climate variation than to climate change. TINGEM and RIVINGTON (2009) simulated the yields of certain crops with and without adaptation. They considered new sowing dates and hypothetical improved varieties. Future yield losses were thus clearly limited. Similarly, BUTT *et al.* (2005) set out their results both without adaptation and with a set of theoretical adaptation options: economic options, crop combinations and varieties resistant to high temperatures. Here again, these options clearly increase future yields. Finally, Ricardian studies examine total adaptation. However, it is not possible to give detail in the results about what options are used and the impact of climatic changes without adaptation. Furthermore, this method does not take the costs of transition into account and hence overestimates the profit drawn from the adaptation.

A decrease in agricultural yields under the effect of climate change

Numerous articles and reports describe projections of yields in sub-Saharan Africa in response to environmental changes (CHALLINOR *et al.*, 2007). But all these documents are focused on a particular country or group of countries lay emphasis on a crop or a specific variety and use different methodologies (an empirical or mechanistic model to simulate yields, different regionalisation methods, different climatic models or scenarios, taking the effect of CO2 into account). It is therefore fairly difficult to have an idea of the overall impact of climate change on agriculture in Africa and above all of the uncertainties accompanying these projections. ROUDIER *et al.* (2011) performed a meta-analysis of the results in the literature, compiling the results given in 16 recent publications on the subject to form a yield database for the future. Figure 2a shows that the sign of the relative change in yield between the present and the future is negative in most cases, with a decrease in yield of some 10% in comparison with the present. However, this figure holds strong uncertainty as the distributions of the responses display considerable spread, varying from -40% to + 80% depending on the case. Taking into account atmospheric CO_2, which has a fertilising effects on plants although this is still not well known and is poorly represented in models (LONG *et al.*, 2006; TUBIELLO *et al.*, 2007 b; AINSWORTH *et al.*, 2008), mitigates the negative effect of climate change although the combined impacts of the environmental changes (climate and CO_2) are negative overall.

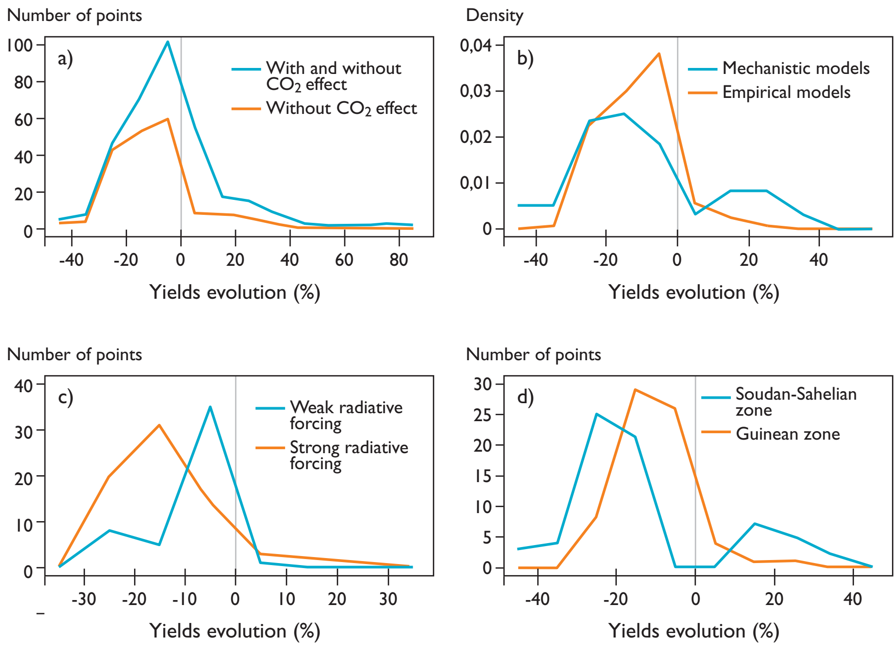

Figure 2.
(a) Distribution of relative changes in yield in West Africa between the present and the future in 16 recently published studies (in blue). The same distribution is shown in orange but only for the studies in which the effect of CO2 on plants is not considered.
(b) As in (a) but with distinction made between the results based on mechanistic models (in blue) and those based on empirical models (in orange).
(c) As in (a) but with distinction made between results for weak (blue) or strong radiative forcing (orange).
(d) As in (a), but comparing the results for the Sudan-Sahelian countries (in blue) with those for the Guinean countries (in orange).
Source: from R*OUDIER* *(2012).*

It is also interesting to see that even if the dispersion of the results from the use of mechanistic models is stronger (which is logical as these models are less constrained than statistical models), the sign of the change of yield that they predict is the same as that of empirical models (Fig. 2b). The amplitude of the impacts of climatic change on yields appears to be modulated by the intensity of radiative forcing. In other words, the higher the concentration of atmospheric CO_2 considered in these studies (distant time horizons, economic scenarios with high emission levels such as A2), the stronger the negative impact expected in yields (Fig. 2c). This observation highlights the importance of taking into account CO_2 emission reduction by mitigation measures that can limit the impacts on agriculture in West Africa. Finally, Figure 2d shows that climate change has a differential impact according to region in West Africa, with the Sahelian countries being harder hit than the Guinean countries. This meta-analysis was extended to a larger set of publications (52 articles) to show the expected impact of climate change on the yields of 8 major crops in Africa and Asia (Knox *et al*., 2012). The latter authors show an 8% decrease in agricultural yields by 2050 in both regions. In Africa wheat yields will fall by 17%, maize by 5%, sorghum by 15% and millet by 10%. Because of a limited number of studies and also contradictory results, Knox *et al*. (2012) were unable to show results that were as clear-cut and robust for rice, cassava and sugar cane crops.

The respective influence of changes in temperatures and precipitation in yield scenarios

We can now examine the climatic variables that cause this negative impact in the existing studies and in particular the respective roles of temperature and precipitation. Changes in these features are both major determinants in the recent trends observed in agricultural production in sub-Saharan Africa. Both the increase in temperatures and above all the decrease in precipitation have led to production deficits since the 1970s (Barrios *et al*., 2008). Although the effects of precipitation have been dominant in recent history, as is shown by the strong link between rainfall and millet productivity in Niger, the situation might be completely different in the future. Indeed, Schlenker and Lobell (2010) show that the increase in temperature forecast by models is much stronger than that of precipitation, which is generally smaller than the historical standard deviation. Furthermore, the authors use empirical modelling of the climate-yield relation to show that the marginal impact of the change in the standard deviation of rainfall is smaller than that of a change in the standard deviation of temperatures in the future. Even if rainfall were not to change in the future, yields would decrease by about 15% as a result of the increase in temperatures that would shorten cropping cycles and increase moisture stress as a result of increased evaporation. According to Schlenker and Lobell (2010), changes in precipitation nonetheless have an impact, but smaller than that of temperature. Depending on whether rainfall increases or decreases in the future, the impact on yield could be amplified by a factor of two – respectively -10% and -21% if the median change is considered. This finding is coherent with that of Salack (2006) who showed that warming (+1.5°C) would inevitably have negative effects on the yield of a millet variety, even if these effects may be mitigated by an increase in precipitation.

Another way of addressing the respective effects of warming and variations in precipitation on agricultural yields was proposed by Sultan *et al*. (2013). The authors performed a set of simulations using the SARRA-H model (Dingkuhn *et al*., 2003) for several millet and sorghum varieties at a set of 35 meteorological stations covering 9 countries in West Africa during the period 1971-1990. The authors then used the delta method to superimpose incrementally at local meteorological stations temperature anomalies of from 0°C to +6°C with 1°C steps and/or relative precipitation anomalies ranging from -20% to +20% with 10% steps. SARRA-H model simulations were performed to quantify the yield response to these temperature and/or precipitation anomalies (Fig. 3).

It is seen that the negative impact on simulated yields caused by a 2°C temperature increase in Africa can be compensated by a 20% increase in rainfall. In contrast, when warming exceeds 3°C, a deficit in simulated yield is seen, whatever the rainfall anomaly considered (within the interval of variation -20% to +20% that was considered to be realistic as we used the minimum and maximum projections of the models CMIP3 and CMIP5 for the region as a base). Projection of the temperature and precipitation response of all the CMIP3 and CMIP5 simulations (all the models and scenarios are merged in the figure) shows that these projections for 2030-2050

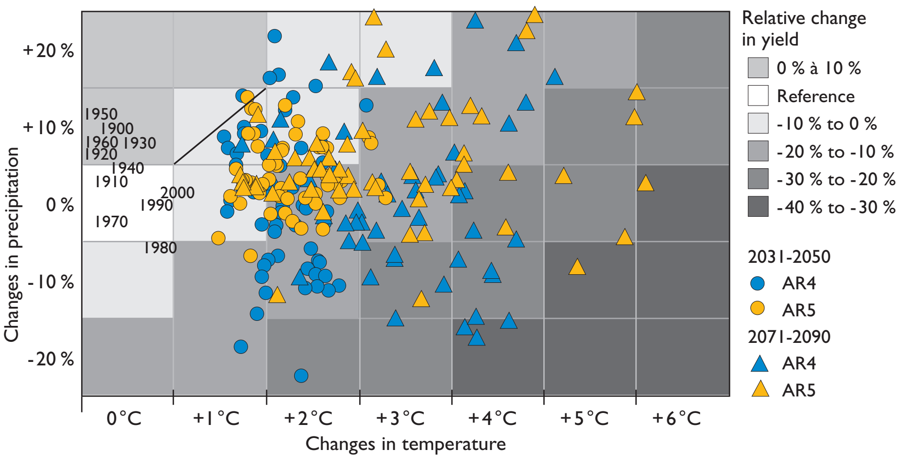

Figure 3.
The effect of changes in temperature and precipitation on average yield.
Relative change in yield (%) in comparison with the 1961-1990 reference period or 7 temperature scenarios (abscissae) and 5 rainfall scenarios (ordinates).
The results are shown as the means for 35 meteorological stations in West Africa and 6 sorghum and millet varieties.
The blue triangles and circles represent future changes projected by several GCMs of CMIP3 (AR4 in the figure) and three IPCC scenarios (B1, A1B, A2) respectively for the periods 2071-2090 and 2031-2050.
The projections of CMIP5 models (AR5 in the figure) and of RCP scenarios (4.5, 6.0 and 8.5) are represented by orange triangles and circles.
The temperature and precipitation anomalies observed since the beginning of the century using CRU data are also shown by decades ('1940' in the figure means the 1941-1950 anomaly in comparison with 1961-1990).
All the changes in yields are significant at a 5% confidence level except for those in the box marked with a diagonal line.
Source: IPCC (2014)

correspond to a yield response range varying from -10% to +10% with a majority of negative to nil impact (from -10% to 0). However, all the projections using the period 2070-2090, whatever the model and/or scenario, display a yield response range that decreases from slightly (between -10% and 0) to strongly (to -40%). The variations in yield response in the future are largely dominated by the effect of temperature, with warming of up to +4°C in the projects of models CMIP3 and CMIP5 in Africa, thus confirming the findings of BERG *et al*. (2013) and SCHLENKER and LOBELL (2010). It is interesting to observe that these temperature variations and precipitations projected by the models and their impact on yields are very different to those observed during the 20th century. It can be seen in Figure 4 that past climatic anomalies are distributed along a vertical axis (precipitation anomalies characterise the variations from one decade to another) while projection spread markedly along a horizontal axis (temperature variations are discriminant in the projections). The projections of past and future decades and their yield response are thus clearly distinct in the figure. This shows that climate change and its consequences as projected by the models CMIP3 and CMIP5 are going to be something completely new that will be like nothing seen in Africa since the beginning of the 20th century. This underlines the scale of the future (and present) challenge of adaptation to climate change: how is it possible to adapt to an unknown (and uncertain) world?

A contrast between the western and central Sahel in the yield scenarios

Uncertainty about the future of precipitation in West Africa is also a very limiting factor for refining yield projections in response to environmental changes. Indeed, there is no agreement between climate models with regard to the impact of climate warming on rainfall in the Sahel (COOK and VIZY, 2006; DRUYAN, 2010), with some models mentioning possible aridification and others predicting increased rainfall in the future. Nonetheless, a few recent studies (BIASUTTI, 2013; MONERIE *et al*., 2013, 2012; PATRICOLA and COOK, 2010; BIASUTTI and SOBEL, 2009) have found a robust signal between the different CMIP3 and CMIP5 models, showing a late start to the monsoon in the west of the Sahel and increased rainfall at the end of the winter period in the central Sahel. This contrast between the western and central Sahel in terms of the evolution of rainfall is not found in temperatures which, in contrast, display warming along a latitudinal gradient with the northern regions of the Sahel warming more than those of the south. The increase in temperatures in the mid-21st century—exceeding +3°C in some places—is so marked that there will soon be nothing similar in recent history (BATTISTI and NAYLOR, 2009). Quantifying the

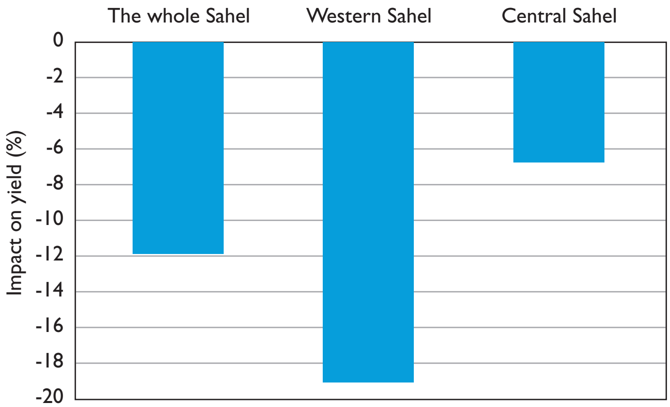

Figure 4.
Simulated response of sorghum yield to climate change.
The relative change (%) in average sorghum yield
during the periods 2031-2060 and 1961-1990 in scenario RCP8.5.
The results are shown as average for 9 GCMs,
two crop models and three sorghum varieties.
The responses are calculated for 13 stations distributed in the Sahel (left),
6 stations in the west of the Sahel (middle) and 6 stations in the central Sahel (right).
Source: after Sultan *et al. (2014).*

impact of this shift in the seasonality of the monsoon, overlying the negative effect of warming on crops (Sultan *et al.*, 2013; Roudier *et al.*, 2011) can be particularly important for identifying crop varieties (early or late) or practices (sowing later or earlier) capable of limiting the impacts of climate change.

Figure 4 shows the response of sorghum yields to climate change simulated by the two agronomic models SARRA-H and APSIM (Sultan *et al.*, 2014). It is noted that climate change causes sorghum yield loss of some 12% in the mid-21st century throughout the Sahel, which is strongly coherent with the figures found in the literature (Roudier *et al.*, 2011). However, the impact differs greatly between the western and central Sahel. Indeed, yields losses are particularly high in the western Sahel (around 19%) as a result of the combination of warming and decreased precipitation at the beginning of the rainy season. In the central Sahel, temperature and precipitation operate in opposite directions—warming causes yield loss whereas increased rainfall at the end of the rainy season is favourable for growing sorghum. However, in spite of an increase in rainfall, the rise in temperatures dominates in the sign of climate change in the central Sahel, as yield losses of about 7% are observed in the mid-21st century. Comparison of the response of sorghum to climate change in the two fertilisation scenarios shows that an increase in inputs makes the crop more vulnerable to changes in temperature and precipitation with greater losses when more inputs are used. This finding is coherent with numerous studies that show that climate risk increases with intensification (see Affholder, 1997 for example).

Conclusions

Anticipating climate fluctuations and changes is primordial for Sudan-Sahelian Africa. The quantification of the agronomic impacts of climate change requires the setting up of often complex methodology using tools taken from economics (emission scenarios, farming household decision models) from climate science (climate models and projections), agronomy (agronomic models) and statistics (regionalisation and bias correction), each with their share of error and their limits. In spite of these uncertainties, it has been shown that a decrease in grain productivity in the future is plausible as an effect of climate warming. This yield decrease is particularly marked in the western Sahel where the effects of a decrease in rainfall and a rise in temperature will be combined at the horizon 2050. However, the challenge to be met lies not as much in estimation of future yields that is deterministic and probably unfeasible but in the quantification, ranking and reduction of the uncertainties related to projections of climate change impacts. The framework of the new international projects for the intercomparison of regionalisation methods CORDEX (Coordonated Regional Climate Downscaling Experiment) and for the intercomparison of agronomic models (AGMIP: Agricultural Model Intercomparison and Improvement Project) will most certainly mark a turning point leading to better allowance for this uncertainty through coordinated studies focused on the impacts of climate on agriculture. Such studies have previously been performed in a very isolated, fragmented manner. However, there should be no waiting for further certitudes before thinking about adaptation measures that are both scientifically relevant and socially acceptable as today's climate has already had an impact on the resources of rural populations. Nevertheless, the study of vulnerabilities and of adaptation to environmental changes requires dialogue between biophysical sciences (climate, hydrology, agronomy) and human sciences (demography, history, anthropology, economics). This multidisciplinary approach is crucial in addressing the question of adaptation to environmental changes in which the response of societies is set in overall social changes and in which the climate variable is far from being the one and only factor in the vulnerability of Sahelian societies.

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Part III

Social changes in rural populations

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Sellers of gari (maize flour) in Dassa (Benin, 2013).

Introduction

Bénédicte Gastineau

How will rural societies in Africa adapt to the climate risks and uncertainties to come? Although there is still considerable uncertainty with regard to the scale of future climate changes in Africa, it is clear that they will come and that societies will have to face them—some exposed to rises in temperature, others to changes in the rainfall pattern, more arid soils, etc. Analysis of farmers' practices shows that they have great capacity for adaptation and innovate continuously to address variability in climate and environmental resources and also in reaction to economic, political and population changes. Rural African societies are dynamic. Whether focused on crops or pastoral activities, whether located on the coast, in the Sahel or in forest, their socioeconomic organisation and farming systems change and adapt continuously (Bourgeot, 1994; Carpentier and Gana, 2013; Rabearimanana *et al.*, 1994). This generally enables these societies to remain on their land in spite of the environmental risks and uncertainties.

Faced with the unprecedented climate changes announced by the works of the IPCC, politicians, civil societies and scientists are wondering about the capacity of rural societies to respond to future changes to the environment (loss of soil fertility, changes in rainfall regimes, etc.) or even to anticipate them (Inter-réseaux, 2010; ADB, 2012). The 'Escape' programme is part of this approach. Social science researchers in the programme are addressing social dynamics interacting with environmental dynamics. This means meeting a 'methodological challenge' to describe the dynamics that operate at these very different spatial and temporal scales. How can local changes (at the level of a village, a household, a farm, etc.) be observed in relation to global changes (at the scale of a continent or the world)?

Is it possible to separate the ‘environmental impact’ from all the other components (economic, cultural) of the context in the changes observed in rural societies?

For the best possible analysis of the interactions – more than the relations – between rural populations in Africa and their environment, the Escape programme has favoured an interdisciplinary approach, applicable to social sciences too. Joint work by demographers, anthropologists, sociologists, geographers and historians allows reflection incorporating the various scales of time and space while hinging different observations units: farm, field, village, family or even individual persons. Interdisiplinarity also makes it possible to show that the relation between environmental and social changes is neither ‘mechanical’ nor ‘automatic’ and that an interface or mediation is required—between production modes and consumption modes for example (SGHAÏER and PICOUËT, 2004; VÉRON, 2013).

It is thus reminded in Chapter 11 that rural societies in Africa have always shown proof of great capacity for adaptation to environmental changes by modifying their farming practices. Comparison of the situations in Niakhar (Senegal) and Djougou (Benin) shows in Chapter 12 that farming systems are not unchanging and farmers now use ‘hybrid’ systems that are between extensive and intensive. These innovations in farming systems can be seen as a response to environmental changes and also to economic and/or social changes, such as a need for cash related to new modes of consumption (motorcycles, telephones, improved dwellings). This seamless agrarian transition is based on farmers’ know-how and uses rural societies’ endogenous capacity for adaptation.

The responses of individuals and families to changes in the environment can take many forms and not be limited to farming. Escape programme scientists have laid stress on the complexity of societies and the variability of responses to changes, thus refuting a direct link of cause and effect between climate variation, the increasing scarcity of natural resources or a decrease in soil fertility, for example, and socio-demographic behaviour.

Migration is a good example: migrants do not move because of the constraint of a single factor (climate change or shock, for example) but because of a complex set of factors (economic, social, demographic, etc.). This is illustrated perfectly for Mali and Benin in Chapter 13, for Senegal in Chapter 14 and for Niger in Chapter 15. It is true that environmental changes can intensify migratory movements or change a few features (such as the calendar and the duration), but rural people leave their villages for many reasons: a desire for independence among young people, men and women and/or seeking a job to earn cash (for a dowry, to fund a farming project, a child’s education, etc.) and/or a strategy of diversification of household incomes, etc. In return, migrants are vectors in the changing of rural societies through knowledge gained during migration, farming or non-farming investments made possible by earnings during migration, etc. The mobility of rural people is not a failure to adapt to climate changes but clearly one component of adaptation among others. Furthermore, migration does not always mean leaving farming.

The importance of the play of scales is very well illustrated in these chapters. The results of the Escape programme confirm the need to reposition the questions related to climate or environmental changes—whose issues are often at the macro scale—in time, space and local contexts. For example, a look at nearly two centuries of evolution of Tuareg society in Imanan in Niger is provided in Chapter 16. The authors thus examine changes in arable and livestock farming through the history of colonisation and political struggles, but without ignoring the role of climate shocks and changes and especially the droughts of the 1970s and 1980s.

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Chapter 11

Rural populations faced with environmental hazards

African experiences

Bénédicte Gastineau, Moustapha Gibigaye, Frédéric Kosmowski, Agnès Adjamagbo, Théodore Houngbégnon

Although the exact and experimental sciences (mathematics, climatology, oceanography, geomorphology) have a fundamental role to play in forecasting and in analysing the past and future climate, the same applies to the social sciences whose role is to shed light on the social and human dimensions of changes. One of the notions often used in social sciences with reference to this question is adaptation[1]—analysing how populations adapt to environmental changes and events (increasingly strong inter-annual variations in rainfall, soil fertility loss, scarcity of land, forest and water resources, etc.). Focus in the social sciences has been on the environment in the broad sense rather than what is strictly the climate in order to show how rural societies organise themselves and adapt to survive in contexts of uncertainty or risk.

In the first part of this chapter we describe the research work conducted on this question. We shall return to three results in social sciences: first the matching of the management of environmental resources and forms of social and family organisation in rural societies, then the fact that adaptation is an old feature of these societies and finally the complexity of forms of adaptation. We base the demonstration on research results in very varied areas of Africa—from Madagascar to the oases of the Sahara by way of West Africa (Senegal and Côte d'Ivoire).

The results of an original survey conducted in the administrative district of Djougou in Benin are then described. The economic and demographic strategies of a rural

1. A common term in social sciences and anthropology, the notion of adaptation is also used by the IPCC and politicians in the framework of climate change. There is a degree of consensus with regard to the needs to implement adaptation programmes and projects for adaptation to climate change by populations in the South.

population obliged to adapt to changing environmental, social or economic contexts are analysed at a 'micro' level. Stress is laid on the complexity of the link with environmental and social change.

The environment and adaptation of rural populations in Africa

Matching the management of environmental resources and forms of social and family organisation

Work in the social sciences on the relations between societies and the climate or the environment reveal 'matching' (JANTY, 2013) and 'intimacy' (PEYRUSAUBES, 2013) between the management of natural resources and forms of social and family organisation.

Water management in sub-Saharan oases is a clear illustration of the way in which populations have become organised for survival in spite of scarce resources. Oasis farmers have developed production techniques adapted to local conditions and also forms of social organisation that closely match these (GUILLERMOU, 1993). Oases require substantial labour for the maintenance of galleries and channels. This is restricting work with little reward. The labour handling irrigation network maintenance first consisted of slaves, then domestic staff or, failing this, younger sons (BADUEL, 1980). Water management thus means that oasis societies are based on a hierarchy of persons, within families as well. This production mode hides a true system of exploitation—especially of young people by their elders. The whole agricultural production system is compromised when there is a shortage of servile labour.

Water management is not possible without a consensus among the population as individuals are extremely dependent on each other. If certain channels are not maintained, the water supply to all the fields is called into question. A minimum of cohesion, cooperation and also sanctions are required for the irrigation system to last. In this context, individual persons are dependent on the extended family. The generations live together and the men—especially the older ones—give orders. Fertility is high, with a preference for male births, and marriage is endogamic, with a distinct preference for marriages between cousins (GASTINEAU, 2007). The mastery of water, a scarce resource, is the basis of social organisation in oases but the rules can be very different in environments where the availability of water is not a problem. Let us examine the example of rice growing in Madagascar where irrigation is also an important issue. BIED-CHARRETON (1970) described anarchic resource management in the Betafo region (Highlands): there was no collaboration between farmers (even between neighbours) and no regulations governing the sharing of water; canals running parallel to each other or crossing were even observed. Water management did not govern social structure as has been seen in oases. In the Madagascan highlands, the availability and mobility of fields—rice fields—are the strong components of the natural environment in which the fabric of social organisation was built. Households have very small farm areas and so it was in their interest to be small. When the children marry they rapidly form a new household. The different generations do not live together, farms are individual, corresponding to a couple (OTTINO, 1998). Women inherit and add their fields to their husbands' farms. If a woman owns more land than her husband, the latter may move to his wife's village and not the opposite (BLANCHY, 2000). Marriages are exogamous. The relations between men and women and between generations are thus clearly different to those observed in Saharan oases.

The two examples—Saharan oases and the Madagascan Highlands—illustrate the strong matching of natural resources and forms of social and family organisation. They are also a reminder that while Africa has very diverse climates and natural resources the structures of families and societies are also very varied. The responses of individual persons, families and societies to environmental events will be able to take many forms and not be limited to just the agronomic aspect.

Adaptation: an old, ceaselessly renewed feature

We face a new environmental challenge today whose long and even short-term consequences for societies are difficult to predict. Nevertheless, we can use past experience to imagine what might be the political, social or demographic responses to the intensification of environmental events and shocks (drought, flooding and hurricanes for example).

Societies display different types of response to environmental shocks or events. The first, most visible, form of adaptation is migration to settle elsewhere. Such 'environmental' migration may be a response to unexpected and violent climatic events. Hurricanes and extremely heavy rainfall can causes massive population displacement (IOM, 2007). Such mobility in emergency situations is generally domestic. The populations do not go very far and often hope to return when the crisis is over.

Slow degradation of the environment with repeated climate shocks (such as droughts) can also cause population displacements. Mention can be made here of the Senegal groundnut basin where from the 1970s onwards a chronic decrease in rainfall and strong population growth led to an intensification of agricultural work that upset the agro-pastoral balance based on crop rotations and fallows—now abandoned. Decreased soil fertility and shortage of land have obliged the population to find solutions for survival, and especially seasonal migration which has become a true institution in this region (LERICOLLAIS, Ed., 1999).

Migration can thus form an integral part of practices for adaptation to environmental constraints. Studies have shown how deforestation and the over-exploitation of land have resulted in the lasting degradation of soil, especially in the cacao regions of Côte d'Ivoire, with farmers having to colonise new, more fertile land continuously to ensure their crop production (Léonard, 1997; Ruf, 1991). A powerful pioneer front thus advanced from east to west in Côte d'Ivoire throughout the second half of the 20th century. The land colonisation strategies used by growers were based on social practices that favoured polygamy, high fertility and the use of labour from other parts of the country and from abroad (Guillaume *et al.*, ed., 1997). But at the time Côte d'Ivoire was a vast territory with very fertile primary forest and low population density[2].

However, an environmental shock or increasingly numerous climate events do not necessarily intensify migration flows. Migration is often considered as a last resort (Brucker *et al.*, 2012). What other adaptation approaches are possible?

Ivorian rice growers in confronted with increasingly marked inter-annual variations in rainfall have developed various adaptation strategies ranging from changes to the cropping calendar to crop diversification (cassava, maize, yam, etc.). New foodstuffs and dishes from other ethnic groups were thus added to their diet (Doumbia and Depieu, 2013). Farmers continuously revise their knowledge and practices to keep climate risks to a minimum and achieve better mastery of resources to ensure food security. Adaptations may be either endogenous or proposed by the state or private stakeholders. The farmers take them and use them, possibly modifying them to make them acceptable for their social and economic context.

The emergence of farms centred on the family unit consisting of a man, his wife/wives and their children is considered as one of the structuring social features of plantation economy societies, especially in Africa (Quesnel and Vimard, 1999; Chauveau and Dozon, 1985). Thus the growing autonomy of nuclear families (in contrast with generations and relations living together) in the Madagascan Highlands is an example that can be considered to be an adaptation. The land area available and the frequency of climatic events partially determine the numbers in residential groups. When production conditions are no longer such as to provide work and food for all the persons in a household, the unit divides—the temporary or permanent departure of one or several members can be decided. Households use various strategies in 'bad years' (too much rain or not enough, a hurricane and a lean season that is too long, etc.): withdrawal of children from school and the use of child labour are two 'adjustment variables' used by households in case of an unexpected shock (Robilliard *et al.*, 2010). Conversely, if the number of persons forming the residential unit is too small in the light of resources, farming households may choose to actually adopt or host children among their relations, to call on foreigners to work on the farm or delay the marriage of young adults so that they stay and work on the farm. This requires fairly flexible forms of social and family organisation. There are many adaptation levels both in Madagascar and elsewhere in Africa (Brucker *et al.*, 2012), including mobility, change of the marrying age and/or the rules of inheritance and residence, the sending out or hosting of children, the schooling or not of children and even fertility (Adjamagbo and Delaunay, 1998; Delaunay, 1994).

2. However, conditions changed from the 1980s onwards: faced with the scale of deforestation in the country, the government set up forest protection policies: in the west, the pioneer front hit its natural limits and, above all, coffee and cacao prices fell drastically on the international markets and gradually resulted in these crops showing poor profits.

Adaptation: what to and how?

The studies performed show the complexity of human societies and the considerable variability of responses to environmental changes. Adaptation is found to be an incessant process of reconstruction of agricultural production conditions and forms of family and social organisation as a result of climate events and changes of course, but also of various other socio-economic, political and institutional factors. Caution is required. This is not a question of establishing a determinist link between 'environmental changes', 'perception of these changes', 'modification of farming techniques and production' and 'social change'. Indeed, it is difficult to separate the impact of environmental conditions from those of other possible factors for change. So the question of migration is a complex one. Environmental migratory dynamics exist but numerous other factors influence the migratory choices made by households (BRUCKER *et al.*, 2012). A recent study conducted in the Yemen concerning regions in which climate change already has an impact on the living conditions of populations shows that a very large proportion of migration is stimulated first of all by socioeconomic and not environmental factors (JOSEPH and WODON, 2013). Likewise, HENRY *et al.* (2004) show all the complexity and diversity of the causes and procedures of migration in Burkina Faso. No direct link has been shown between rainfall conditions (and climatic conditions more generally) and the intensity of migration in rural Burkina Faso, including the drought zones where climatic stress could have been expected to form strong encouragement for the departure of populations. In contrast, features such as ethnic group, type of work and level of education are clearly identified as individual variables that account for migration (HENRY *et al.*, 2004).

Farming populations in Africa face up to a great number of constraints on which their social and family life and farming practices depend: constraints as varied as volatile agricultural prices, limited access to inputs or seed, problems of local or national political governance, limited access to basic health or education services, poor road systems and problems of security. Changes in farming practices or in the demographic behaviour of rural populations are therefore 'multifactorial'. Environmental problems are thus only one of the many constraints that the population have to face up to.

This synthesis of research results comes out in favour of taking into account the complexity of the relations between social change, climatic events and environmental changes. We now describe the results of research carried out in rural Benin in order to illustrate this complexity.

The research was conducted within the framework of the programme '*Changements environnementaux et sociaux en Afrique: passé, présent et futur*' (ESCAPE)[3].

3. ESCAPE is a programme funded by ANR CEP&S 2010. It groups 8 research laboratories at several French institutions (IRD, CIRAD, CNRS, etc.) and partners in the South (Université Cheikh Anta Diop in Senegal, AGRHYMET and LASDEL in Niger, CEFORP in Benin, the Direction Nationale de la Météorologie in Mali, etc.).

Strategies for forcing up to environmental events (Djougou local authority area)

The district of Djougou is the Donga department in northern Benin and about 461 km from Cotonou, the economic capital of the country. The population was 266,522 in 2012 (INSAE, 2013). In 2011, 40% of the population were below the poverty threshold[4], 10% more than in 2009 (INSAE, 2012). Access to health care is still difficult[5]. Households are an average of 8.8 km from a health centre[6] and the cost of medical care is an obstacle. Likewise, access to public education is not always easy in Djougou (shortage of classes and teachers). However, the raw school primary attendance figures[7] (115% in 2011-2012) are fairly similar to those of Benin as a whole (120%) (Ministère des Enseignements Maternel et Primaire, 2012). In Djougou, rates of completion of primary schooling[8] are smaller than the national average (63% against 71%), especially for girls (52% against 66%) (Ministère des Enseignements Maternel et Primaire, 2012). Less than 30% of adults (over 18) are literate (45% in Benin as a whole) (INSAE, 2012).

The economy of Djougou is based mainly on farming. About 75% of households are farmers (INSAE, 2013). With a Sudan-Guinean climate, a rainy season (April to October) and a dry season (mid-October to mid-April), the main crops are maize, yam, millet, cassava and sorghum; soya and cowpea are also grown[9]. Cash crops such as cashew, shea and nere are also grown. Some households are market gardeners around reservoirs and in low-lying areas. The rearing of cattle and small ruminants (goats and sheep) is a marginal activity at the scale of Djougou. Most farmers own their land (75% of households in 2013). Farms are small and the average cultivated area was estimated to be less than 3 ha in the 2012 season (INSAE and MAEP, 2013).

The strategic position of Djougou as a crossroads and transit centre is a fundamental advantage for trade and in particular for shipment of farm produce and processed goods. Indeed, trade in manufactured goods and crop and animal products form the second economic activity of Djougou after crops and livestock. In addition, there are

4. The threshold defined by the Institut national de la statistique et de l'analyse économique (INSAE) was CFAF 138,754 per person per year in 2009 and CFAF 120,839 in 2011.

5. As regards health, the Djougou district is part of an area covered by three districts: Djougou, Copargo and Ouaké. The 22 sub-divisions of the health zone each have at least one public health centre.

6. Ministry of Health (2013), health statistics yearbook.

7. This is the ratio of the number of pupils, whatever their age, at primary schools to the number of children with the official age for primary school education (6-11 years old). As children over the official age (11) are enrolled in primary education (either because they have started school late or have repeated years), the second figure may exceed 100%.

8. The percentage of children with the official age for completing primary education who have in fact completed this.

9. In 2012, 91% of Djougou farmers grew maize, 79% grew yam, 62% grew cassava, 53% grew sorghum and 44% grew millet (INSAE and MAEP, 2013).

several regional markets in the district (at Djougou, Kolokondé, Partago, Bougou and Kpaouya) and purchases are made there by traders from nearby districts and certain neighbouring countries. The sale of agricultural goods should not therefore involve any difficulties for producers if the agricultural sectors are sufficiently well organised.

The climatic and environmental conditions in Djougou can be considered to be favourable for agriculture. There have been no strong variations in rainfall in recent years. Annual cumulated rainfall has not changed since 1993. It is greater than that observed during the previous decade that was marked by major droughts (the 1980s) but less than the cumulated figures in the 1960s and 1970s. Annual rainfall depth has been stable since the 1990s but there have been strong annual variations and changes in the dates of the beginning and end of the dry season. Temperatures have continued to rise, mainly at night (+ 1.2 °C in Djougou since 1950) and at the end of the dry season, that is to say at the start of the farming season. These changes have already led farmers to change some of the farming practices. In Djougou, as elsewhere in Benin, farmers display an ability to adapt (KPADONOU *et al.*, 2012). For example, the recent use of short cycle maize varieties by Djougou farmers can be seen as an adaptation to the changes in environmental contexts (see Chapter 17).

The data produced within the framework of the ESCAPE project mean that we can show that farmers are overcoming environmental risks by adaptations in farming but also by means of socioeconomic and demographic strategies. However, although adaptation capacity is real and has many features, it can be supposed that it will weaken if environmental problems worsen, given the context described above (limited access to health services and education, frequent poverty, low literacy level).

As part of the work of ESCAPE, we surveyed 1,120 households distributed in a zone whose boundary lies 2 km to the east and west of a transect running north and south of the town of Djougou (with the centre of the town excepted). A household is defined as a group of persons, related or not, residing in the same space. It is also the site of a great number of decisions including those by the head of the farm and concerning the farm. We conducted sociodemographic and agricultural surveys of households, questioning heads of household (1,120) and then persons identified as being responsible for a farm (1,232). A person responsible for a farm is someone who has farmed at least one field during the last three rainy seasons, with responsibility for the organisation of the work and the choice of crop.

We have data concerning the composition of each household (number of members, family ties with the head of the household) and certain characteristics of individual persons (age, sex, activity, education, etc.). We also collected a few farming data at household level (area of land owned, area cultivated, fallows). Next, each head of farm was interviewed about his farming practices (type of crops, changes in varieties during the last 10 years, introduction of new crops, changes in cultivated areas, etc.) and his perception of climatic events and environmental changes (rainfall, wind, temperature, etc.).

Results

Large households but a fairly small reserve of labour

Djougou households have an average size of 8.3 persons. They generally consist of a man (referred to as the head of the household) his wife (or wives), their child/children; a brother and his family may be added to this group. The large size of households[10] results in particular from the fact that polygamy is frequent in Djougou: a third of the heads of households have second wives. It is also explained by high fertility: heads of households declare an average of 8.7 live births[11].

Farming uses mainly family labour with the proportion of farms using paid farm labour being less than 50% for all crops except for cash crops such as soya, groundnuts and cotton. Household size and composition are thus important information. The average number of residents is 4.7 adults (over 15 years old); however, only 1.4 of these say that they are agricultural workers. The others are either at school if they are young, do not work or have other jobs. In particular, a great majority of women have non-agricultural work, with 63% working at the date of the survey and with 72% of these persons working outside farming. They work mainly in trade (especially in processed agricultural products) and crafts. Of the men who work (82% of those over 18), 88% are crop and/or livestock farmers. The non-agricultural work of women and certain young adults can be seen as a pluriactivity strategy and a diversification of household income. Women's income means that the household has cash (for expenditure on health, schooling, the purchase of consumers durables such as clothes, etc.). However, women's work off the family farms is dependent on the environmental conditions and their jobs can be affected by unforeseen environmental events. For example, this is the case of women aided by development projects and sometimes organised as associations that make shea butter.

Food security of the household is a priority

Heads of farms must therefore organise farm work with comparatively limited labour. Because of this constraint, they organise their work and choose crops that allow them to first and foremost produce enough to feed their family. Food security is the main priority. This is why more than 80% of farmers grew maize (85%), yam (83%) or cassava (60%) during the 2012 rainy season. Cash crops such as soya and cotton are not a priority and are grown by 25% and 20% of households respectively. Livestock is fairly little developed: 31% of farms owned at least one sheep and 16% possessed at east one ox at the time of the survey.

Households can sell their production—and even their food crops— when the harvest is large enough. Thus during the season preceding the survey slightly less than half of the farms had sold part of their yam and maize crops. Some farms have surpluses

10. In 2011, average household size in rural Benin was 5.3 persons and the average for the Donga department was 7.1 (INSAE, 2012)

11. The synthetic fertility index was 4.9 for Benin and 4.7 for the Donga in 2012 (population and health survey).

every year and others only in good years. The good and bad years depend of course on climatic conditions but also on the dynamics of the household. Illness or the death of a member of the household can also call farm production into question: for example, money earmarked for the purchase of inputs may be used to pay for health care or a funeral. The sudden death of an adult also reduces the household labour force.

Nevertheless, fewer than 15% of the households stated in the survey that they had been short of food for the household in 2010, 2011 (10%) and 2012 (9%). Food security is thus assured overall in this survey zone[12], either because the farmers grow enough to cover their consumption or because they have sufficient cash income to purchase foodstuffs when their own production is too small.

The diversification of income: a necessary strategy that must not compete with agricultural work

Among this population in which cash savings are rare, non-agricultural income is essential for facing a climatic event or a demographic shock (death or illness). The diversification of income is neither specific to Benin nor a new strategy. The strategies of rural households in poor countries today feature the maintaining and continuous adaptation of a range of activities (Ellis, 2008). Diversification is a possible response to the inter-annual variability of crop yields and hence of farm incomes; it limits the risks inherent in agriculture. Pluriactivity can be either by the specialisation of individual persons (some work on the land while others have non-agricultural jobs) or by cumulating several activities by one person. In Djougou, migration is one of the ways of diversifying sources of income. Some young girls are sent to Cotonou as domestic staff and young boys may also leave the household to work in town. Children from the Djougou district are thus strongly represented in domestic labour in the economic capital (Kouton *et al.*, 2009). Migration limits household size, and hence expenditure, and the income (in cash or in kind) generated by the children's work may be received by the parents. It is probable that more young children leave in bad years but parents may put their children on the urban labour market in both good and bad farming years to anticipate the irregularity income from one year to the next (Affo, 2014).

The activities of the various persons must be organised to prevent pluriactivity from compromising the farming activity of the household. The head of the farm—who is often also the head of the household—is responsible for this. He must ensure that all the workers can be mobilised for agricultural tasks and that those leaving for long-term migration are not essential on the farm. The availability of workers depends on a large number of factors (health, schooling, migration). An increasing number of young adults migrate temporarily to Nigeria. They leave to take paid jobs in the rural frontier zones where commercial farming is developing (Bonnassieux and Gangneron, 2015).

12. This was confirmed at the scale of the Djougou administrative area where only 13% of households were classified by INSAE as suffering from food insecurity (Insae and Maep, 2013).

According to the latter authors, the migrants are 'groups in a position of inferiority'—younger children and adults form who access to land is difficult, etc. They do not migrate as part of a diversification strategy but rather in a quest for emancipation in the face of the authority of their parents, for example. Today, the heads of farms do not always have the legitimacy needed to hold back young adults who wish to migrate to gain personal experience and their own incomes (Droy *et al.*, 2014). This is obviously a strong constraint in the management of family labour and means that young workers are not available during the farming period. Thus the use of paid labour from elsewhere is not rare, especially for cash crops: 70% of cotton growers and 52% of soya growers had used paid farmworkers. Family labour is still dominant for food crops but is not always sufficient: 50% of growers of maize, 41% of growers of yams and 28% of growers of cassava had hired at least one paid worker from elsewhere to help them.

Effective adaptation strategies?

The society we observed in Djougou is therefore dynamic, with social and family structures and persons who modify the way they function and their practices (agricultural, economic and demographic) in order to ensure their food security and their economic survival. Nevertheless, these survival strategies might show their limits in the face of new environmental changes and events.

First of all, the effectiveness of pluriactivity and the diversification of income as observed today in resisting increasingly frequent shocks or events can be questioned. Work for women outside family farms is often strongly dependent on the farming sector and then sensitive to climate shocks. This is the case of the processing of shea[13]. Several Benin associations and international organisations and cooperation operations are trying to support shea butter production in the region by stimulating the modernisation of production facilities, helping women to store the nuts and making it easier to obtain funding[14]. Many other initiatives are aimed at supporting women's work in rural areas: the organisation of women's groups for the purchase, storage and sale of maize and cotton (e.g. the Kpebouko supported by the Netherland Development Organisation), the organisation of the milk sector for the manufacture, conservation and sale of Peul cheeses (Belgian Development Agency), etc. Many of these projects for rural women are aimed at creating paid activities to enhance their autonomy and diversify the income of their households. Very few guide women to sectors that are less sensitive to climatic disturbance and less dependent on natural resources.

The capacity for adaptation of households would obviously be greater if they had better 'human capital'. However, education and literacy levels are poor in Djougou and this limits the possibility of lasting placing on the non-urban labour market and even the development of agricultural activities. School attendance and vocational

13. Without technical changes, the yields of shea areas may decrease in a context of climate change (rise in temperature and change of the rainfall regime) (Gnangle *et al.*, 2012).

14. An example is the very active cooperation between the Djougou town council and the town of Évreux (France) http://www.evreux-djougou.org/

training (agricultural and non-agricultural) are not sufficiently accessible. Nearly 7 persons in 10 surveyed were uneducated and only 1 in 10 had attended secondary education[15]. National data show that the literacy rate of 15-24-year-olds in Djougou in 2011 (51%) was 15% lower than that of Benin (65%) (INSAE, 2012).

This lack of training also contributes to the under-employment of young adults[16]. More than half of 15-24-year old working population in the Djougou district are under-employed (INSAE, 2012). Furthermore, these young people often have no access to land (BONNASSIEUX and GANGNERON, 2015) and are economically dependent on their families. Job opportunities in the non-agricultural sectors are comparatively limited locally and even on an internal migration basis. The strong urbanisation of Benin occurred without industrialisation and urban jobs are rare in both the formal and informal sectors. Young adults and even some married men may choose to emigrate to Nigeria in the hope of earning wages (DROY *et al.*, 2014).

Rural households are still massively dependent on their agricultural income in an economically difficult context. Poorly organised sectors, farmers' organisations that are not always efficient (MOUMOUNI, 2013), limited storage capacity and limited on-site processing capacity make farms very fragile and incomes very variable from one year to the next.

For all these reasons (little scope for pluriactivity, rare non-agricultural jobs, poor human capital, variable economic context) and doubtless many others, rural families are vulnerable and their survival often depends on their endogenous capacity for adaptation and innovation. This vulnerability will increase with an intensification of unforeseen events. Nobody knows if family adaptation capacity will be sufficient to face this new situation (rising temperatures, more frequent violent rainfall). It is therefore urgent to reduce the vulnerability of rural people by raising the educational level of young people, improving their health, making farm incomes secure, organising marketing channels and enhancing the processing of local agricultural produce.

Conclusion

A very great number of research programmes in the fields of agronomy and geography have undertaken the study of the implications of climate change for agricultural production modes (ABIDJI *et al.*, 2012; ETWIRE *et al.*, 2013). Research in social science has been focused on adaptation and innovation strategies and even on the forms of resilience of African families in a context of environmental change. The review of the

15. According to the 2011-2012 demography and health survey (EDS), fewer than 1% of adults had completed secondary education. These results corroborate those of our ESCAPE survey.

16. Under-employment covers all works as understood by the International Labour Office (ILO) who fill one of the following conditions: they work part time, wish to work more and have availability for this; they work part time (and are in a situation other than that described above) or full time but have worked less than usual during a reference period because of partial unemployment (temporary lay-off) or bad weather.

literature and our results for Djougou confirm that this a complex question and that there are many forms of adaptation to face an unforeseen event or an environmental change. Mentions can be made of changes in family structures (polygamy, cohabitation of generations, etc.), the calendar and intensity of fertility, strategies for the schooling of children, the involvement of women and men in agricultural activities, procedures for the handing on of land, pluriactivity and migration.

Although these changes have been observed clearly and described in the literature, their relation of cause and effect as regards the environment is often difficult to establish, especially when climate change is concerned. This results to a considerable extent from the fact that climate changes are at a macro level whereas sociodemographic analysis is only pertinent at the level of households, that is to say at a micro level. Furthermore, it is very difficult overall to identify what in the context—whatever it is—triggers a change in sociodemographic or economic strategies. Individual persons, households and families are set in contexts that may change, like the climate or the natural environment.

An intensification of migration, rendering households nuclear, changing the rules of marriage, decreasing fertility, etc. are responses to multiple changes of different kinds and with different temporal features and among which global climate changes that weight on agricultural production conditions form part. If an unforeseen environmental event can trigger a crisis (agricultural, economic, political or social), there is often prior vulnerability to this event. It can reasonably be considered that the more the population has access to public services (education and health), to banking services (loans) and to agricultural extension, the more protection they will receive from the authorities regulating agricultural prices, and the more organised they will be. Their vulnerability will decrease and they will be more capable of standing up to a shock or an unforeseen event.

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Chapter 12

Land rights and fertility management

Two different perspectives: Djougou (Benin) and Niakhar (Senegal)

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Élodie ROBERT

Introduction

Here we consider land as a support for cropping, pastoral or agropastoral activities at two study sites (Fig. 1) of the ESCAPE programme: Djougou (the villages of Angara, Alhéri and Sew Sewga) and Niakhar (the villages of Ndoffane Mouride, Ndoffane Nomad, Sanghai and Sob) with two aspects analysed:

– control of land (rights of use, appropriation, inheritance, customary or legal institutions) distributed socially according to groups belonged to and the date of settlement;

– management of soil fertility (rotations, fallows, taking new land, organic and inorganic fertilisers).

In Niakhar, the land rights systems are no longer those of 1960-1980. The authority of the old lineages has weakened in favour of family farm units, while in Djougou the land chiefs have kept their administration powers and maintain land rights inequalities between 'native farmers' and ' non-native herders'. In both cases, within the farming systems the family units currently have a degree of autonomy as regards lineage institutions and it is sometimes difficult to distinguish between right of use and right of ownership. Furthermore, heritages are regularly divided between several men (brothers, sons) thus stimulating a land fragmentation process.

Soil fertility management in Djougou is based on long fallows and the clearing of new land. However, the increasing density of agriculture is gradually shortening fallows and yields have dipped strongly. Fallows have practically disappeared in Niakhar and fertilisation is now based on the livestock/plant cycle by returning organic matter in the fields produced by livestock. In spite of this system, which has become extremely sophisticated (composting, organic matter placed in sowing holes, etc.), farmers also report decreases in yields.

Comparing relative performances (in land rights or fertilisation methods) with population dynamics leads to wondering about the limits of the two systems. Indeed, demographic data show that the population of the district of Djougou doubled from 1992 to 2013, increasing from 34 persons per km^2 to 68 persons per km^2 (INSAE, 2013). The population of Niakhar district increased from 111 persons per km^2 in 1985 (LOMBARD, 1995) to 140 persons per km^2 in 2000 (DELAUNAY *et al.*, 2006), and then to 169 persons per km^2 in 2008 (ANSD, 2009).

As the increase is strong, demographic trend forms a limit for both these farming systems. In Djougou, how can the end of fallows that is taking shape be envisaged? What fertilisation technique will replace it? In Niakhar, how can sustainability be designed for the small family farms that would seem to be at the end of the densification process? How can this family farming based mainly on food crops succeed in feeding households?

Our hypothesis is Boserupian and neither that of collapse (famine, massive migration) nor an increase in poverty but one of changes (continuous processes) or transformations (technology jumps, changes in the rule for access to land, etc.) of farming systems. According to Ester Boserup (1970, 1985), the dynamics of farming systems has strong links with demography. However, unlike Malthus for whom farming systems

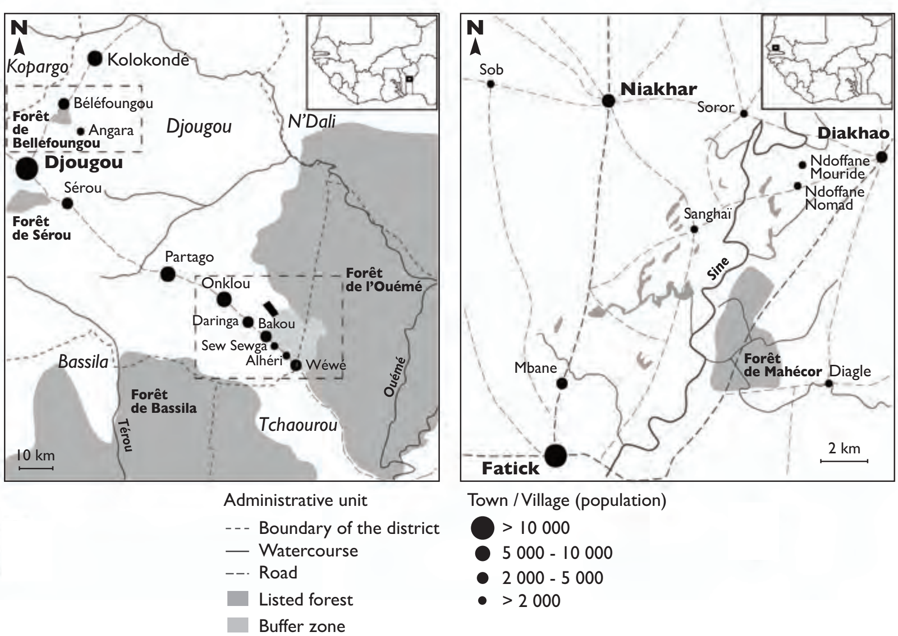

Figure 1.
Study zones.

defined their capacity to feed a limited population until they failed (epidemics and famines), Boserup considered that population growth is a source of changes and innovations. These changes can be in the form of rapid transitions (the adoption of animal draught, etc.) or a continuum (the gradual replacement of fallows by organic fertilisation, etc.).

In Djougou, environmental and technological potential indicate a comparatively large margin for intensification. In contrast, the public policies aimed at land registration and the emergence of a landowning class carry a risk of weakening land rights, in particular for social groups with no territorial legitimacy. The risks linked to the land rights in Niakhar seem to be mainly the result of the fragmentation of land at each inheritance. Scope for intensification is markedly smaller than in Djougou. The system is already extremely sophisticated (little loss of organic matter) and has only minor potential based on the last areas available ("*bas-fond*"[1], French expression) and/or the farming calendar (crops staggered in relation to rainfed crops). This is demonstrated by a few successes in market garden crops and watermelon.

Administrative rights and rights of use

In the two agropastoral areas Djougou and Niakhar, land is not a simple production element as in northern countries. The reality of land rights has nothing to do with the combination of *usus*, *fructus* and *abusus* or 'imported' legal vocabulary ('owner', 'tenant', 'sharecropper', 'tenant farmer', 'lease' etc.). There is no question of property as understood in Roman law in these rural areas (PLANÇON, 2009). Land rights form part of the social relations that make a distinction between the lineages of the first persons settled (first installations enhanced by mythicized stories) and all the other social groups. Beyond its obvious economic functions, land has a political, social and even magico-religious aspect. The question of land can therefore be understood only with the taking into account of the kinship system and the foundations of the authority of those who control land (LERICOLLAIS, 1999).

Djougou

Land rights are held by the land chiefs who all belong to the Yom socio-linguistic group except in the north of the district and beyond its eastern boundary where the Bariba live. 'Ownership fact is not like right of ownership' (KOUASSIGAN, 1966: 132), but rather like that of a small landed aristocracy. The relations between this aristocracy and the others do not form a mercantile relationship but territorial, social

1. According to ALBERGEL (1988), 'they represent specific and essential "environment units" within tropical landscapes. These are the preferred convergence axes of surface waters, hypodermic flows and phreatic tables'. These lands are interesting for secure and diversified agriculture.

and political subjection. 'Agrosedentary' people do not pay for use of the land (in the form of sharecropping or cash) but contribute to the community activities of the village (weddings, religious festivals, etc.), by their presence and/or 'gifts' in kind (sorghum, a cock, etc.). They grow the crops they want on the land attributed to them and keep the entire harvest. They have a few restrictions, such as the forbidding of tree planting as this would form a lasting marking of areas, an act of appropriation of land reserved for those with rights of possession, the land chiefs. The latter (and their lineages) thus exercise control of land (LE ROY, 2000) or a right of administration, of regency in the village area. They take decisions concerning grants of the land still free—if the village has any— and settle land conflicts (inheritance of rights of use, rights of possessions) and cases of animals loose in the fields.

These regulation functions are generally still active but a few old rules like the forbidding of tree planting have become flexible in some villages, and where the picking of néré *(Parkia biglobosa)*,when it is still performed, is no longer supervised by the chiefdom.

The relations between farmers and landholding authorities have changed somewhat. In certain places, such as Angara (a Lokpa village), they have been dissolved because of the absenteeism of the land chief (Yom): regulating land and settlement conflicts are handled by the heads of families and the village chief and the forbidding of the planting of fruit or forage trees is not applied any more.

Historically constituted land rights make a distinction between several fairly closed categories of populations: the lineages of Yom land chiefs, the other Yom, the other 'agro-sedentary' farmers (consisting of Lokpa, Ditamari, DjugureeBe Peuls[2] and many minorities) and finally itinerant herders (BarguuBe Peuls and MbororooBe Peuls[3]). Distinction is made in the rights between the descendants of the founders of the lineage and all the others; these are the base of identity and form the frontier between 'natives' and 'non-natives'. However, the time since settlement brings a relative land security of ; rights of use and rights of possession can thus be seen as a continuum that can be expressed as follows:

– holders of rights of possession and administration: the kings/land chiefs and their lineages;

– farmers, linked to the former (they accompanied them when the village was founded or possess a degree of seniority in the village area): Yom, Lokpa, and DjugureeBe Peuls;

– all those who arrived late, like the Ditamari from Sew Sewga who do not have the right to plant trees and must change fields often (sometimes every year).

All these groups are farmers, with strong ties to the land. Alone among the Peuls, the DjugureeBe, former livestock farmers and now crop farmers (or crop and livestock farmers), have close links with the Yom. They have historical functional relations that still operate and are often friendly with them. They reared livestock either for

2. Literally 'the Peuls of Djougou' who arrived in the region and settled, starting in the 19th century and then arriving in waves of migration until the mid-20th century.

3. The BarguuBe Peuls came from Borgou and the MBororooBe Peuls came from northern Nigeria.

themselves or on behalf of certain Yom. This practice has not been abandoned completely but it is becoming increasingly rare. Nevertheless, pastoral herding is still practised and is even increasing in the district, but in other forms and by other groups, BarguuBe and MbororooBe Peuls. They are still considered as foreigners and their rights to land are practically non-existent (GANGNERON, 2011). It is possible to add a fourth group to the typology above, consisting of these herders who are barely tolerated in 'interstitial spaces'. In fact they are in a situation of land relegation and are only tolerated where there are not (or not yet) any issues or agricultural pressure in enclosed zones (far from lines of communication and village centres). Animal husbandry and crop farming are thus 'disconnected' as they are practised by distinct social groups with few functional links (trade, fertilisation, barter, etc.) and whose activities are also in competition with each other on the same land. In fact, the case of these herders is quite special as the practices of transhumance and nomadism[4] do not follow the same logic as that of sedentary farmers. Transhumant pastoralists from the Borgou have their territorial base there (village, permanent dwellings, families and fields), where nomads (MbororooBe) have light camps that can be moved rapidly. Neither aims at obtaining land but rather its resources on a seasonal and/or opportunist basis. This does not place them in a landholding approach (ROBERT & GANGNERON, 2015). Their difficulties stem more from the absence of pastoral corridors and farm sub-division that hinder the movement of livestock and carry risks of stray animals in fields and hence conflicts with crop farmers and crop and livestock farmers. The land in the district has a history of agriculture, constituted and administered by groups of sedentary farmers whose customary institutions do not award pastoral legitimacy to transhumants and nomads and the latter do not possess institutions that would enable them to draw up rules for the joint management of land and resources. They only have 'narrow spaces' in a corpus of customary law formalised by and for sedentary farmers.

Finally, whether the question is one of possession/administration rights or rights of use, heritage management is always patrilineal among farmers. On farms (nuclear or enlarged family type), the oldest man of the lineage (brother, father, grandfather) always plans and manages the land and the farming calendar and those with the lowest social status (unmarried young men, women) are always subservient.

Niakhar

In Niakhar, lands authority comes from the founders, with the first waves of migrants setting up 'lamanats'. These are large administrative areas centred on village cores that grow when the lamanes entrust new arrivals with land to clear. Payment in kind was made by these new farmers, thus marking the power of the lamanes, but the land allocated could not be taken back. Rights of use were acquired gradually and provided a degree of landholding security, which could be inherited. The rights of

4. Transhumance and nomadism can be considered as two forms of pastoral animal husbandry. The former refers to regular seasonal movements of groups – here the BarguuBe from Borgou. The latter in the district concerns the MbororooBe, who originated in northern Nigeria, and who move with families and camps. Their movements are less regular and their installations may last for years.

the founders, known as ‘fire rights’, were passed on via uterine lineage (the eldest son of a sister), as in Sob or Petiaka (a hamlet linked with the village of Sanghai). Awards of land by the lamanes to arrivals in subsequent waves resulted in inheritance rules that were agnatic in this case (from father to son; LERICOLLAIS, 1999), and ‘axe rights’, that is to say for those clearing land. Whether agnatic or uterine, the lineages for village cores can still be recognised by the names of the families who are often organised in quarters consisting of several dwellings, forming the highest rank of the land management scale.

The agricultural management of land is handled at the *mbind,* a term indicating the houses and a dwelling unit for the extended family under the responsibility of an elder, or *ngak* – kitchens – which are sub-units of the *mbind* consisting of nuclear families. The *ngak* is the basic unit of production and consumption and has comparative economic autonomy in relation to the *mbind*.

The lamanes have disappeared, replaced in the inheritance of land rights by the ‘great families’ and even more by the *mbind*. Semi-structured interviews even refers to divisions of land within the *ngak,* thus giving land independence to the nuclear family (LERICOLLAIS, 1999). Land does not ‘leave’ the *mbind* or the *ngak* but is shared between several sons. Many families have lived in the same *mbind* and on the same land for several generations, thus displaying great homogeneity and great population continuity. The few great families have almost always been there since the founding of the village.

The change in the management scale has been accompanied by changes in inheritance regulations, with the passing on of land between generations in uterine lineages (from maternal uncles to nephews) now ancient history.

This twin evolution is doubtless the result of a combination of the growth of the power of the state, and in particular, the law of 1964 (concerning the national domain) and the weakening of the landed aristocracy since the death of Mahécor, the last king of the Sine, in 1969. The law of 1964 stipulates that unregistered land is in the national domain and cannot be ‘appropriated’. Inspired by socialism, it recognises rights of use but not of ownership (no sales and no transactions are permitted) for those who farm. It specifies the ‘withdrawal of this land […] either because of inadequate farming or if the person concerned ceases to farm it personally, or for reasons of general interest’ in Article 15. The rural council elected by universal suffrage (FAYE, 2008), handles the application of the rule and is responsible for withdrawals, but only in the case of a conflict reported to it. As for the rest, land authority has shifted from the old lineages to smaller, *mbind* and *ngak* units. Inheritance—now from father to younger brother or elder son—gives them joint authority on management of the farming calendar and land. Divisions between sons have increased and elder sons seem to have lost their precedence, except for benefiting from the land closest to dwellings and that are better manured and hence more productive, as reminded by GUIGOU *et al.* (1995: 203): ‘The eldest son takes the land closest to the house, the next one takes the next land and the youngest takes the land furthest away’. Fieldwork for the ESCAPE programme revealed the increasing independence of *ngak* with the sharing of land that was sometimes even organised when the father was alive.

The rights instituted by the state did not put an end to the old rules immediately. For example, a few hybrid forms of heritage were observed between sons and nephews until the end of the 1990s. These heritages between several children in a context of continued population growth and the saturation of land caused worrying scarcity, with the fragmentation of parental farms with no possibility of clearing new land. In this context of saturation, the 1964 law awarding rights to farmers has reduced the possibility of loans (in Sob in particular; pressure on land is not as strong in Ndoffane Mouride and Ndoffane Nomad and the situation is intermediate in Sanghaï) and procedures have changed. The lender takes care to loan land for only one year whereas loans for at least a crop rotation were common before the 1964 law.

Independence in land management is leading to considering right to land in ways other than those of the period of the lamanats and the great families that regulated land rights. Today, family organisations grouped in dwelling units and farming systems grouped in production/consumption units form the land management system. Nevertheless, in the Sanghai and Ndoffane Nomad areas, the rights of management and use of the old lineages are still visible in the bottom land (the Khoer, Soss and Diouf families in Sanghai: '*me yoto na bandiale*', literally 'it is me that stays in the "*bas-fond*"). This land was little affected by landholding pressure and was only a minor resource that was nonetheless useful for grazing and a little rice crop. The current pressure on land has changed the situation and the issues are such that the old families issue reminders about their rights to these areas that are a focus for numerous market garden crop initiatives and are the last nearby grazing areas that are not cultivated.

In short, land does not change hands (inalienable), the management scale approaches that of production units and it is handed down from father to son, with several sons being able to take their fields when they marry and form their own *ngak*. Land may be fragmented in the *ngak* or managed by a real or classificatory elder at the level of the *mbind*.

The fragmentation of land at each generation is a logical consequence of the inheritance system (land is left to several children) and landholding pressure (no free land remains to be used for cropping). In addition, the introduction of the plough in the 1960s and 1970s accelerated the movement towards extensive crops. LERICOLLAIS (1972) noted these limits in the early 1960s when population density reached 80 to 100 persons per km^2 in the old farmland and was already concerned about the effects on farming systems (marginalisation of livestock, reduction or disappearance of fallows, etc.). The observation is the same 50 years later but the trends are more marked as the population has grown by 50% and livestock grazing and the areas operated per *ngak* have decreased considerably. At the scale of *ngak* farm production units, the land managed is some 5-6 ha in Sanghaï and Ndoffane Nomad, 3 ha in Ndoffane Mouride and a little more for isolated farms[5].

Finally, the extremely homogenous population (in contrast with that of Djougou) is mainly Serer and analysis of the complex of rights concerns practically only the Serer. The few Toucouleur families are not particular wanting or under territorial constraints.

5. The information was collected by interviews in which maps were used, allowing an assessment of areas.

The question of landholding pressure is not discussed *ex nihilo* but shows all its meaning when seen in relation to farming systems and in particular with soil fertility, the other factor that we examine here.

Maintening soil fertility

Djougou

Djougou is in the Sudan-Guinean zone (AUBREVILLE, 1949) with average annual precipitation of 1,220 and 1,330 mm in the 1990s and 2000s that marked the return to normal climate conditions after the deficit of the preceding decade (1,070 mm in the 1980s). This rainfall makes it possible to grow remarkably varied crops—those with high water requirements such as yam and maize (the largest crops). Sorghum, cassava, cotton and groundnut are grown in other districts with less rainfall. Secondary crops are added to these and for some families can form a substantial complement; in particular these include cowpea, voandzou and millet (SDAC, 2010). Market garden crops (mainly during the rainy season) and cashew are also grown but the areas devoted to them remain modest.

Grown as an open field rainfed crop, yam requires rich soils and is always first in the rotation, followed two or three years of crops such as maize/sorghum, groundnut/sorghum or groundnut, cotton and maize for example. Cassava is quite common at the end of the rotation. Soil fertility is maintained by long fallows and burn-off before the land is cultivated again. Although it cannot be compared with that of Niakhar, population pressure nonetheless has direct effects on the duration of fallows, which used to be some 10-15 years or more and is now about 3 years. The area cropped formed only 40% of the area of the district in 2012 (LEROUX, 2012; ROBERT *et al.*, accepted) but is increasing strongly. It grew from 13% of the total area in 1991 to 22% in 2000 and 36% in 2006, (JUDEX *et al.*, 2009: 85) and land for clearance has become more rare close to villages. No land is available at Sew Sewga and Alhéri since the 2000s.

Maintaining soil fertility is based essentially on fallows and, secondarily, on clearing new land. Both these alternatives are becoming delicate under the pressure of population. As in Niakhar, the farming system is based on the core family and inheritance concerns several boys when they marry. The parental land is thus fragmented—divided between several children at each generation. Maintaining the crops required for the new family is not achieved by affecting the cultivated areas (these are still 5 or 6 hectares per production unit) but by shortening fallows, thus calling into question the capacity for restoring soil fertility. Only the compound fields fertilised with animal manure maintain their production levels. Animal manure is fairly rare for the rest, except for a few DjugureeBe who have managed to continue livestock farming (a few dozen animals) alongside crop farming.

Crop and livestock production are generally separate. Cattle raisers grow few crops or none and arable farmers posses little livestock or none at all. The two worlds are sociologically distant from each other and do not cooperate any more than in northern Benin where no manure contract is recorded[6] (DE HAAN, 1997). The major herders in the region are now the MbororooBe and the BarguuBe. Their relations with crop farmers are still strained and the latter sometimes forbid the grazing of crop residues after the harvest. But agronomic solutions for transferring organic matter to fields are simple and the results are good (LANDAIS and LHOSTES, 1993). The problem is a sociological one, crop and livestock farmers have frequent conflicts for soils resources and the movement of herds and legitimacy (livestock farmers are considered to be foreigners and have no rights). The reciprocal confidence needed for the combination remains to be developed.

Finally, the inorganic fertiliser alternative involves purchase. This would require the reallocation of part of the monetary resources generated by cash crops, but these are barely enough for other expenditure (health, education, transport, etc.). Inorganic fertiliser is used only on maize and cotton.

Niakhar

In both Niakhar and Djougou, land management and the farming calendar are organised with two targets and in two different ways. On the one hand are the family fields whose crops are for feeding the household, with the head of the family controlling the calendar. On the other, small individual fields cultivated by women, youngs or even the head of the family himself are used for cash crops. The two different approaches are not necessarily in competition with each other but are hybrids. Calendar priority is awarded to the food crops in family fields but the family and its members would also like to have monetary income. Part of the cash from the individual fields goes to the family (to cover medical expenses, school expenses, building materials for the home, etc.) while the rest covers more personal expenditure (purchase of pagnes, telephones, etc.). The cash crops in Djougou are cotton, cashew and rice; market garden crops and a proportion of the food crops (maize and yam) may also be sold. The choice of crops is more limited in Niakhar, where there is less rain and no signs of a recovery[7]. Among rainfed crops, groundnut, sold by all families, and watermelon can locally generate substantial complementary monetary income. Millet is the basic food crop.

The usual 3-year crop rotation (early millet, sometimes combined with long cycle millet, or sorghum, followed by groundnut and then fallow) from the end of the 19th century until the 1960s (LERICOLLAIS, 1972) became more simple with the gradual disappearance of fallow as a result of landholding pressure and the introduction of draught ploughing. At Sob, pressure has led to saturation. All the usable land is cultivated and fallows have disappeared. They are holding on a little better at

6. In these oral contracts livestock is left in the fields to be manured. In return, the crop farmers supply the livestock farmers with millet or sorghum.

7. 520 mm during the period 1968-1987, 463 mm for 1988-1998 (DELAUNAY *et al.* 2003), 440 mm for 1999-2007 (VANDERMEERSCH and NAULIN, 2007; CHIPAUX, 2005; ANSD, 2009).

Sanghaï, Ndoffane Mouride and Ndoffane Nomad. The difference between Sob and the other sites is not the cultivated areas, which are nearly identical, but lies in the maintaining or disappearance of fallows. It is therefore not certain that if the families at Sob had more land they would grow more but would probably reintroduce fallows in the area currently limited to the biennial alternation of millet and groundnut or to intercrop millet and groundnut and then millet or sorghum and beans for example. The maintenance of fertility in this system cannot be based on fallow and implies the import of organic matter to the fields. The Serer have an agropastoral tradition and the livestock/crop agronomic cycle is incomparably easier to manage than at Djougou. In spite of the overall reduction in head of cattle, fertility is still based on livestock dung and urine. The very sophisticated recycling uses several pathways. Sheep, goat, donkey and horse manure is collected at resting places near dwellings. For those fattening livestock—common at Sob—all the manure is collected in the pens. It can then be just stored (sometimes composted in heaps or in pits) before being incorporated into fields (before the crop is installed). When the *le ngak* has cattle they are tied up to pickets in the dry season and moved every three days. These practices show that a densification process in under way as 'traditionally, the main supply of organic matter was from the paddocking of livestock on fallows during the cropping season and, in the dry season, on the fields to be sown with millet' (LERICOLLAIS and WANIEZ, 1993).

The organic matter balance is not necessarily excellent insofar as what is incorporated is mainly the reimporting of crop residues given to livestock as feed. Even more sophisticated fertilisation techniques are used for watermelon crops, with application of manure or composts directly in seed holes or furrows. In spite of these techniques for the optimisation of the animal/plant cycle[8], all the farmers are worried about falling yields. Millet yields in the Diakhao region are reported to have fallen from 700-1,100 kg/ha to 350-600 kg/ha in a decade (according to the *Plan local de développement de la communauté rurale de Diakhao*, 2001). Furthermore, isolated trees and hedges that formed a typical feature of the Serer landscape until the 1970s and 1980s have not survived well because of pressure on wood supplies, the end of fallows (that left young trees two or three years to grow and thus allowed them to emerge) and agricultural mechanisation. Certain species were pillars of field fertilisation, such as *Faidherbia albida* whose numbers had already decreased by 34% from 1965 to 1985 at Sob (LERICOLLAIS, 1999) and the trend has continued since then.

The use of inorganic fertiliser is rare as in Djougou. Structural reforms ended aid in 1989 but the state resumed subsidies for fertilisers in 2003-2004; they were modest at first and increased in 2008 following the world increase in agricultural commodity prices at the end of 2007. Then, after being nil in 2002 subsidies reached $9 billion en 2011 (USAID, 2011).

8. A person at Ndoffane Mouride explained that the type faeces and their use according to the season: *loli* – from October to December, the grass still has a high water content, excrement is moist and disappears rapidly; *nour* – from January to March when the weather is dry and the livestock are given water only once a day, the women use the dung for burning; *thoron* – from April to June there is less feed and excrement is small and can last for a year without decomposing; *nawet* – rain decomposes excrement immediately and this is the best.

Finally, with the exception of the *pombod* (field of early millet near the habitats) where manure is applied regularly, yields of other crops are decreasing with the application of a biennial rotation and little organic fertilisation in spite of relatively sophisticated techniques.

Dynamics compared

Population pressure thus has two types of effect: first, land availability through the question of local rights and usages that lead to the fragmentation of farms at the two sites and to the exclusion of the immigrant population of Djougou; second, the maintaining of fertility, which also shows its limits via a reduction or disappearance of fallows and difficulties in maintaining or setting up a sustainable animal/crop cycle. The dynamics that have led to the present situation operated in combined processes—some being slow (continuous process) and other fast (breaks and transitions)—and permanent features at the scale of the last 20 to 30 years.

We provide a synthesis with some information about the context.

Permanent features

The passing on of rights of use are between parents and several sons in both Djougou and Niakhar, but:

– in Djougou, a landed aristocracy splits numerous social groups into ‘native’ and ‘immigrant’; pastoralists suffer territorial and political relegation;

– in Niakhar, the *mbind*/*ngak* have landholding autonomy with regard to the lineages; land is not transferable.

Fertility management is handled in two ways:

– in Niakhar, maintenance is based on the livestock/crop cycle;

– in Djougou, fertility management is based on fallows and secondarily on the clearing of new land. Tension between crop and herders block the integration of crop farming and animal husbandry.

In spite of signs of the taking of autonomy by young social inferiors (in particular young unmarried people who migrate to earn their own living and who sometimes refuse unpaid work for the household), labour is fairly easy to find in both places.

Continuity

Population growth is still strong at both sites:

– densification is continuing in Niakhar, reaching a very high level for a Sahelian environment thanks to strong agricultural intensification;

– densification is continuing strongly in Djougou; environmental potential is still significant but limited by permanent features of farming systems based on long fallows and strictly manual means (no animal draught).

Food-based family farming is still practised in both cases but has gained a distinct monetary aspect because of the emergence of new needs (educational material, health, housing, transport, telephone, etc.). Agriculture now has a hybrid aspect in which crops for sale on the market have gained a substantial position.

A gradual impoverishment of the soil and a decrease in yields are observed.

The fragmentation of land caused by inheritance systems reduces the farm areas held by households.

Discontinuity

Only Niakhar experienced a true break in the 1970s after the rapid generalisation of animal traction (horses and donkeys) and the use of ploughs and seeders.

In Djougou, the first attempts at introducing animal draught have failed. However, a break is possible as the recent land law (2013) that encourages the registering of land may suddenly put some farmers in a fragile position (especially those whose installation was recent), together with itinerant pastoralists not benefiting from customary law.

Boserup's analysis

Population growth—a continuous process at the two sites—is a major point in the dynamics of the systems. Rural densification can be considered as an extra load on the environment but its full significance can only be seen in relation to farming systems and their transitions; it could be 'the mother of innovation', one of the main factors in the evolution and/or change in farming systems.

Boserup's contribution was to have understood this link and to have described forms of intensification, and especially the five procedures for land use in the intensification process (Boserup, 1970). She described them as forest-fallow (the most extensive type with the land left for about 25 years), bush-fallow (with a regeneration time of less than 10 years), short-fallow (lasting for only 2 or 3 years), annual cropping and finally multi-cropping. These forms of land use intensification are accompanied by the intensification of labour, technological jumps and changes in land rights. The two sites can easily be classified in the five forms of land use.

In publications that now date back a long time (1970, 1985), Boserup mentioned that a large part of Africa possessed areas to be claimed for farming and environmental resources were still plentiful in moderately populated areas. She added that there was little scope for earning money from agricultural activities because of the comparative scarcity of markets and the isolation of production areas with regard to consumption areas. These factors, together with the mobilisation of work force consisting of every member of the household (men, women and children) are features of permanence. It is clear that this is no longer the situation at the two study sites: markets (and even distribution or processing and distribution sectors) are now firmly present and neither zone is isolated at all. Sales of groundnut, fattened cattle and watermelons at Niakhar confirm this; sales of livestock are easier at Djougou where there are several cattle re-export markets. Cotton, cashew, rice and timber production are also demonstrations.

What are the future prospects?

FERTILITY, TECHNIQUES AND LABOUR

Niakhar has practically finished with fallows and there is no hope of switching to multi-cropping as rainfall is not sufficient. Intensification is taking another form with market garden crops and watermelon. This is not a double crop on the same land but use of the labour force outside the season for rainfed crops. Indeed, vegetable crops fit perfectly in the farming calendar as they come right after the millet harvests as long as water is easily accessible (until December or January). Watermelons can be grown using the same calendar as that of rainfed crops but they are also suitable for staggered production during the same periods as vegetable crops. This is therefore the optimisation and densification of the work calendar and also a process for using the "*bas-fonds*" and the banks of the Sine that was not of great interest until recently.

Another intensification pathway would seem to concern the evolution of agricultural technology that remains much as it was in the 1970s and 1980s after the adoption of animal draught. The hypothesis of a switch to motorised tools seems excluded because farms are small and fragmented and the income likely to be generated would be too small with regard to the investment needed. In spite of the small returns from farming, the use of inorganic fertiliser seems to be a more probable hypothesis, at least if the fertiliser subsidy policy is maintained.

Shifting our focus a little from agricultural activities to activities as a whole, it is seen that many diversification initiatives are emerging or growing stronger. These are not in the fields but still in the *ngak* (with the aim of family subsistence). The diversification activities are not new, strictly speaking, but form an increasingly common source of income in a relatively open world. The older activities (healer, now dispensed for cash, builders of granaries, makers of bricks or mattresses, blacksmiths, saddlers, etc.) are now accompanied by 'trades': masons, shopkeepers, tailors, drivers, mechanics, carpenters, cooks, educated activities (in administrations, associations, aid programmes, etc.). These strongly growing occupations are gradually changing the rural human landscape. It is timely to observe this not just through agricultural activities but in a pluriactivity complex that maintains a dense rural fabric.

On the Boserupian scale, land use in Djougou is between bush-fallow and short-fallow and not (yet?) accompanied by technological jumps. The district has a margin for the intensification of soil and labour management, at least as regards two aspects.

Introducing livestock in the farming cycle would allow the import of organic matter but would run up against the obstacle of the total lack of connection between native farmers and immigrant herders. It is difficult to imagine a true rapport between the two groups. In addition, the old systems of *confiage* between DjugureeBe and Yom have almost completely disappeared. The forbidding of livestock farmers to allow cattle to graze harvested fields seems to be a major trend likely to aggravate the cleavages between crop and pastoralists. The emergence of an agro-pastoral continuum as with the Serer in Senegal does not seem possible: the divisions described above seem to be insurmountable and the incorporation of cattle farming[9] by the groups of crop farmers seems unimaginable for the moment.

9. However, small ruminants (sheep and goats), and even pigs among the Ditamari, are common but never in sufficient numbers to fertilise the fields.

The second aspect concerns the introduction of animal draught. Unlike the case in Niakhar, cultivation is still manual, with tools limited to the daba and the machete. Agents from the CeRPA (*Centre régional pour la promotion agricole*) tried to introduce draught cultivation in 1990-2000 but the attempt failed and animal traction, ploughs and carts are practically non-existent. Failures of mechanisation by exogenous processes are not rare and there can be several kinds of reason. Knowledge of the most productive technologies is a prerequisite but not sufficient for its adoption. The plough—known in Europe for 3,000 years, took a long time to become common (Boserup, 1970: 62). First of all, knowledge of the management of draught animals (feed rations, identification of symptoms, etc.) is not obvious and the farmers in Djougou do not have the experience; in addition, a pair of oxen is a substantial investment, even with subsidies. But the determinant factor is doubtless the relative availability of family labour. The family logic of the farming system is still fairly significant and the organisation of the entire household (children and unmarried persons of both sexes, wife/wives) is the rule. However, movements towards autonomy can be felt. Young people affirm themselves more strongly; individual fields and diversification initiatives are often driven by a desire for individuation. Migration from the district to the towns in the south and to Nigeria display evolution. Whereas this long expressed the strategies of heads of families—sending young people to earn a little money elsewhere while conserving sufficient labour at home—its is increasingly the desire of the migrants themselves. And they do not hesitate to leave, against their fathers' advice, to find a paid job doing agricultural work that they refuse to do free of charge for the family. The mobilisation of family labour is thus tending to become more difficult. Furthermore, the gradual monetisation of farming leads to supposing that a fresh attempt to introduce draught cultivation would have more success than in 1990-2000.

Land

Like the problem of soil fertility, hypothesis of increasing land tenure insecurity is not the same in both sites. In Niakhar, only the fragmentation of farms seems to be a cause of difficulty and the population, whatever their community—Serer, integrated or Toucouleur—does not seem to be threatened. If they continue, public action and public land policies are not a source of worry either.

In contrast, the hypothesis of a point of rupture in Djougou (and in all rural areas in Benin) can be put forward. The relations between people and the land are undergoing 'reification': ancestors' tombs are neglected, ceremonies abandoned and sacred places cultivated. The land, in the hands of authorities that intend to conserve revised customary law privileges, is beginning to be the subject of the first transactions. Unthinkable some 20 years ago, this is becoming feasible (that is to say morally acceptable) and the land tenure fragilisation of those who have only secondary rights is a real risk. As regards the state, the rural landholding plans (*plans fonciers ruraux*, PFR) resulting from the land laws of 2007 and above all 2013 can make these transactions possible legally. They are presented as a simple technical facility aimed at collecting oral customary rights and transposing them into written legal documents. But they are more than that: they are a political tool for land reform.

They cause (or accompany) a shift in the sets of rights (to land, resources, gathering, farming, of land chiefs, farmers and graziers) towards forms closer to a market system. The PFR in Djougou is in the initial stages and is to award new rights by drawing up 'land certificates' as a base for launching a land registration procedure (Le Meur, 2008; Lavigne Delville, 2010). In effect, these certificates form only 'presumption of ownership' and can be turned into land deeds, that is to say property as understood in Roman law[10]. In this system, some beneficiaries of these new rights—land chiefs and a few notables in their lineages—become owners with rights of use, usufruct and sale. Relations with land are thus tending to turn into economic relations, with fragility for the great majority of future non-owners. Thus the rights to land and environmental resources of groups considered as immigrants (farmers and, above all, pastoralists) might be contested.

Conclusion

We have not observed what is strictly a rapid change, a conversion from one farming system to another more intensive and productive one under the effect of demographic pressure. The two systems continue, one with fallow, plentiful labour and manual techniques and the other on land cultivated each year and with increasingly insufficient application of animal manure.

But the farmers continue to live—often better than in the previous generation. Although they have not (yet) performed an agrarian transition, they use strategies and innovations while assuring the historical function of their farming, that of producing their own food. Initiatives are generally cautious (small fields of cashew or market garden crops, etc.) and are developing and diversified little by little to the point at which they concern practically all families, first in the form of new crops and then by work separate from farming.

The most noteworthy change in family farming at the two sites is that diversification is always aimed at generating cash income. Ways of life inspired by town dwellers' standards have arrived in rural environments. For example, mobile phones and motorcycles are very widely distributed. Housing has changed considerably with the arrival of steel roofing and concrete. Even eating habits have changed, as is seen with the introduction of bread. In Niakhar, one meal in three (the midday meal) commonly consists of rice that has generally been purchased. This has replaced millet or sorghum grown on the farm and that is now eaten only at the morning or at the evening meal. These changes are not Boserupian breaks but the gradual affirmation of 'hybrid' agriculture that continues to serve its primary function of food supplies in spite of the decreases in yields, while also developing cash crops to gain access to the market. The difficulties described in this study have thus not been solved but avoided or overcome by the effect of the hybridisation/monetisation of small family farming.

10. These operations have speeded up since the MCA (Millennium Challenge Account), a United States cooperation agency, has taken land reform in hand alongside the new Ministry of Urbanism.

If the public authorities succeed in guaranteeing the land rights of farmers, whatever group they belong to (by taking a little distance in registration procedures for example) and if they succeed in accompanying them by training policies and subsidies (animal traction, seed, etc.), agricultural densification will do better than enable farmers to survive. It will give sustainable assurance of another function that is essential for small farming, that of supplying towns where consumption is increasing continuously (on this point, see FAO, 2014).

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Chapter 13

The role of seasonal and pluri-annual migration in reducing vulnerability
Hombori and Djougou districts

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Climatic and environmental crises and migration: divergent positions

The role of climatic and environmental crises in increasing migration is a subject for debate (GEMMENE, 2007). When they bring up the worsening subsistence conditions of populations and increasing migration, environmental specialists highlight the preponderant role of irregular, decreasing rainfall on the one hand and soil degradation on the other. Their work contributing to the emergence of an environmental refugee category has received much media coverage in a context of the blocking of frontiers in Europe for fear of a massive, uncontrolled flow of migrants from the most fragile parts of West Africa (CAMBREZY and LASSAILLY JACOB, 2010). Researchers working on the long-term evolution of migration have reserves with regard to the determinant role assigned to climatic and environmental crises in displacements of populations. They accept that shortages and inter-annual variability of rainfall contribute to increasing temporary migration and its changes (GONIN and LASSAILLY JACOB, 2002). However, they consider that migration is related to an interlinking of environmental, economic, social and political factors whose range varies according to the territorial context and the period. Focusing on the climatic and environmental causes of migration carries the risk of hiding other factors that play a role that is just as important if not more.

The increase in migration in the Sahelian and Sudan-Guinean regions is stimulated by constraints—poverty, shortage of work during the dry season, insufficient and irregular rainfall, the high cost of marriage, the subordination of categories in a position of inferiority—whose importance varies according to ecosystems and societies. It is also explained by attractive factors and especially the potential of emigration destinations from the financial and social points of view for personal affirmation, helping the family and gaining new skills that can be used in agricultural or non-farm activities after their return (Mounkaila, 2010). The growing opening of regions to the outside, improvement of means of communication and the generalisation of certain needs also contribute to mobility. A decision to migrate involves cash resources and personal contacts—especially with compatriots already settled in immigration zones. Long distance migration is expensive and involves risks that cannot be taken by the poorest, whose mobility is often limited by lack of money and social capital (Brown, 2008). After a bad harvest, migration to maintain food reserves and find help for the family is often combined with other strategies to achieve subsistence: sale of livestock, paid farm work, small trading, solidarity, gathering substitute foodstuffs, etc. (Yayé and Gado, 2006).

To assess the effect of environmental and climatic factors on migration in comparison with other factors, we analyse the evolution of migration dynamics in a Sahelian district, Hombori in northern Mali, and a Sudan-Guinean district, Djougou in northern Benin[1]. A description of the two districts is followed by examination for each of the characteristics, changes and purposes of migration. We then return to specific features of the contexts of migration and the strategies used by those involved in order to establish differentiation.

Hombori, a dominantly pastoral district where migration goes back a long way

Hombori is an administrative district halfway between the Dogon country and Gao in northern Mali where activity is mainly pastoral. Crop farming is essentially rainfed and covers only 3 to 5% of the district (Cheula, 2009). Estimated at 18,000 in 2009, the population is made up of several ethnic groups. Songhai are the most numerous. In descending order of size, the other groups are Peuls, Tamachek and Dogons. Differences between nobles and communities of servile descent are strong among the Songhai, the Peuls and the Tamachek. Population density is modest at 6.3 persons per sq. km and a third of the population of the district lives in the town of Hombori, the capital of the district. Average rainfall has decreased by a third since the end of the 1960s, falling from 466 mm between 1950 and 1970 to 324 mm since 1990.

1. These surveys were run within the framework of several research programmes: AMMA (*Analyse multidisciplinaire de la mousson africaine*) and ECLIS (*Élevage, climat et sociétés*) in Hombori in 2008 and 2009; ECLIS and ESCAPE in Djougou in 2010, 2012 and 2013. It has not been possible to perform further research in Hombori since 2010 because of insecurity in northern Mali.

Inter-annual variability increased after 1990, making crop and livestock farming more precarious (Mougin *et al.*, 2009). Migration movements to Hombori are not a new phenomena. They form an ordinary pattern for families in crop or livestock farming and make possible the economic and social preservation of agro-livestock groups. However, their features have changed.

Before 1970, migration to coastal countries had composite purposes

Migration of people from Hombori to towns in the coastal countries Ghana and Côte d'Ivoire and to a limited degree to towns in Mali such as Mopti goes back a long way. The most documented movements are those to the Gold Coast (now Ghana) in the 1920s and 1930s. The Sahelian zones played the role of supplier of labour for building towns and developing cash crops, mainly in the coastal regions and, secondarily, in the savannah zones (Dougnon, 2008). In Hombori, as in other Sahelian regions, migration mainly involved young men until the major drought of 1973-74. Most migration was during the dry season for farm work and was driven by the search for work to earn cash. Migration had important social aims. The subordination of members of groups of servile descent among the Songhai (Banney), the Peul (Rimaibé) and the Tamachek (Bellah) by their former masters and that of young people by their elders was strong. Life and work abroad in 'prestigious' coastal metropolises enhanced strategies aimed at independence. But migration was also the fruit of family strategies consisting of economising food by sending young people elsewhere with the hope that they would bring cash when they returned to work in the fields at the beginning of the rainy season.

The Gold Coast was the main destination for migrants from Hombori during the colonial period. Work could be found more freely than in the areas colonised by France and where forced labour was not abolished until 1946. The Gold Coast economy was the most advanced in West Africa until 1950-1960. Much travelling was done on foot because of the lack of roads and means of transport in the Sahelian regions. Relations housed migrants when they arrived. Unskilled labour requirements were substantial in public works and buildings and in factories, shops and markets in the growing cities (Accra, Koumassi) (Verlet, 2005). Many migrants left for short periods—during the 7 to 8 months of the dry season—and returned to their villages for farm work. However, when they had stable jobs or succeeded in opening a shop or a workshop, as was the case of many Songhai in Koumassi (Dougnon, *op. cit.*), they might stay away for several years without going home.

Migration to Ivory Coast grew in the 1960s and overtook that to Ghana, which was in recession. It was the time of the 'Ivorian miracle'; Abidjan was growing strongly and attracted people from the whole of West Africa. Migrants found work easily in factories, at the port, in department stores or with Europeans as domestic staff or caretakers and changing employer was easy. Several young Songhai who left for Abidjan during this period stayed for 20 years and sometimes longer, working as warehousemen near the large shops in the Plateau district or as factory workers near the port. Some of them used their savings to buy cattle when they returned to their villages. A minority consisting of persons from Hombori who had attended school found jobs in sectors that needed qualified workers. Several remained in the country and took Ivorian nationality.

Migrations during the 1970s and 1980s crises

Migration changed scale with the major droughts and food crises of 1973-74 and 1984-85. Food shortages caused a considerable increase in migration and concerned all categories of the population: men, women, old people and all social groups. Contacts were not necessarily maintained with those who left at that time. As has been observed in northern Mali, the drought caused the fragmentation of Hombori families (GRÉMONT *et al.*, 2004). Destinations were much more varied than before the periods of shortage. Under emergency conditions because they had lost everything, many people from Hombori went where they could survive, with destinations including the nearby regions of Konna and Mopti or in northern Burkina Faso. According to the testimony of a village chief, 'those who left did everything they could find to get something to eat'. During and after the major droughts, migration to Ivory Coast and Nigeria grew exceptionally as the economies of both countries were still expanding strongly. According to a Songhai notable in Hombori, the large number of people from Hombori in Ivory Coast and the aid that they sent to their families meant that 'from 1975 to 1985, Ivory Coast was the economic heart of Hombori district'.

After 1990, although droughts were not as serious as they had been during the two previous decades, they marked the beginning of an era in which recurrent problems of subsistence became one of the major causes of migration.

Agriculture is often seen as an increasingly uncertain activity because rainfall is small and displays inter-annual variability. However, the chronic difficulties as regards subsistence are also caused by manual equipment with low productivity that means that the areas cultivated per holding cannot be increased. Only a minority of farmers—generally Dogon—use draught cultivation. Decreasing, irregular rainfall in a context of weak evolution of farming systems and mediocre soil fertility have resulted in a worsening of subsistence conditions in comparison with the 1950s and 1960s. But the marked differences in food self-sufficiency are caused by disparities in equipment and the degree of mobilisation of the labour force. In a survey conducted in 2009 on a sample of 112 farmers, nearly half (46%) had food reserves for less than two months after the harvests and a third had stores for between four and eight months (AGUILHON, 2009). A minority of farmers (7%) were self-sufficient and had surpluses.

Profiles of today's migrants and the reasons for migration

Although most migrants are still unmarried men, the number of households, older men, women and girls who migrate for a season and/or on a pluri-annual basis is distinctly higher than it used to be.

Many young men consider that farm work is unreliable and not very fulfilling. According to a teacher in Hombori, 'when they go two or three years with practically nothing to harvest, the young people are discouraged'. But young people's dislike of farm work does not result only from the irregularity and paucity of harvests. It results from difficulties in meeting personal needs while working on the family farm, unpaid, under paternal authority. The young people in the villages who manage to get by are those who are able to have small jobs of their own—individual farming of a market garden plot, paid farm work or driving cattle—to generate a personal income. Young people who have been to school have often lost the habit of hard work in the fields and would like to leave to earn wages. Their resistance to working unpaid on the family farm is a source of tension and incomprehension by the elders. The latter think that young people are 'lazy, not as tough as they had been and more materialistic' because they have other needs that they can only meet by being different from the family: buying mobile phones, motorcycles, clothes, etc. As a result, young people are tending to stay longer elsewhere.

Migration is also a strategy for saving food reserves. As possibilities for work are extremely limited in most villages during the dry season, many young people and an increasing number of households migrate to regions not far from Hombori in Mali or Burkina Faso, to work to ensure subsistence during the dry season. Before they leave, the grain crops harvested are set aside to feed their old parents who stay and to ensure that there is food when they return for the rainy season. Even if promises to improve daily life by cash contributions are not held, such migration saves drawing on the family granary. Mouths to feed leave in the dry season and muscle for the fields returns in the rainy season.

In addition to the increase in these categories of migration, that of young girls is growing and, to a lesser extent, that of married women who migrate without their husbands. Most work as domestic servants in towns in northern Mali. Such female migration is fairly common among Dogons and in groups of servile extraction, especially Peul Rimaibe. In contrast, the departure of young girls is frowned on and fairly rare in Songhai circles.

Periodic cash remittances from migrants and those made on their return are used to buy food at the two large markets in the district—in Hombori and Wami. The monetary resources provided by migrants often complement those earned by a few local activities: small livestock fattening operations, cattle trade, artisanal activities, paid farm work, the manufacture and sale of charcoal and gathering and sale of forage for feeding livestock. When a job brings in enough money to buy food—which can be the case when the cattle trade expands—the contribution of migrants to subsistence is marginal. In contrast, it plays and important role in families without the capacity for diversifying activities devoted to subsistence.

When the crops are poor, migration is no longer a strategy for the best possible management of limited reserves but becomes a survival strategy and the number of migrants increases. According to a person of authority in the village of Dakakouko in November 2008, after poor harvest resulting from insufficient rainfall, there were some 100 migrants out of a population estimated at 515. During such crises, departures are earlier and returns are later. The cash sent by migrants is used more than usual for purchasing food.

Migrations in an area with smaller potential

At sub-regional level, this change in migration is in an increasingly restrictive context resulting from the economic crises and political conflicts that have occurred in the ‘traditional immigration zones’. As early as 1969, several people from Hombori who had stable jobs in Accra and Koumassi had to leave Ghana when measures were taken for the large-scale expulsion of West African migrants. But at that time Sahelian labour was still needed in Nigeria and Ivory Coast. Since the 1980s, increased unemployment and poverty in Nigeria, Ivory Coast and other countries have caused numerous departures. Emigrants from Hombori were witnesses and victims of the crises in the former immigration destination areas. Some who worked in Lagos lost everything they owned when two million foreigners were expelled from Nigeria in 1983 to appease public opinion upset by precariousness and violence after the end of the economic boom in the early years of oil production.

Several of those who were workers in Abidjan at the beginning of the 1980s lost their jobs after measures were taken to limit the use of foreign labour after companies failed and the labour market shrank. When poverty became more acute in the 1990s, young people from Hombori had to face competition from Ivorians who, in order to live, were ready to carry out work previously considered to be degrading, such as pulling carts. Several were victims of xenophobic violence aggravated by the fostering of Ivorian national identity. Because of the violence suffered, migration to Abidjan of young Bellah from Doungouri, which had been frequent before marriage, practically ceased. As their situation was one of increasing precariousness in various coastal countries, some migrants sent their wives and children back to their home villages.

In the face of these crises and the difficulties encountered on the migration routes—racketing in particular—movements shifted to countries that were geographically and culturally closer. Several migrants were housed and helped by Songhai relatives in Niamey, where they worked as masons or marabouts in particular. In Niamey, several young people in the Bellah village in Doungouri have worked in Niamey as water sellers in Niamey, a common trade among Malians in the Gao region. The gold mines at Essakane near Djibo and Gorom-Gorom in the north of Burkina Faso attracted a growing number of young people and families from Hombori, even though gold panning is considered to be dangerous and uncertain. According to a young Songhai, ‘It’s more by luck than work that you make money in the gold deposits’.

A few people from Hombori tried their luck in towns in southern Algeria and in Libya, but discrimination with regard to immigrants from black Africa in these countries, the bad treatment endured and the frequent expulsions of sub-Saharan migrants have limited the numbers involved in this migration.

As a result of the decrease in paid jobs and the difficulty of gaining a lasting position in the economies in immigration areas, routes have changed and migrants travel according to opportunities for work in areas that are essentially Sahelian, and even Malian. The migrants who do best are those who have a skill (masonry, mechanics, well-sinking) that mean they can find work more easily, even in small places. People from Hombori are most numerous in Bamako, where they work in shops and care-taking. The increase in trade in cattle and in fattening means that young Peuls and sometimes Songhai are readily employed by town-dwellers—especially traders—to look after their cattle. Seasonal migration to closer regions is now more common, with destinations like Mopti-Sévaré and medium-sized towns such as Douentza and Konna. This short-distance migration gives more opportunities than before in small, jobs requiring little qualification: carters, guards, cattle minders, gold panners and shepherds. Earnings are small and irregular—less than those in the former immigration zones. Many migrants, and especially those living in urban areas and who live with their wives and children cannot help their parents in their home village because they have trouble enough ensuring their own subsistence.

Migration systems based on contacts

Being part of socio-professional networks guides routes for migrants and helps them to do what they want to do. In Hombori, as in other Sahel regions, movements are often within village and/or ethnic communities whose members are scattered geographically, often across frontiers (Dougnon, *op. cit.*). Destitution and lack of contacts drastically limit travel possibilities. Those who have nobody to help them to pay for the trip often travel on foot to the nearest places to find work and earn money to travel further. When young people who want to go to large cities do not manage to get together the money needed for the trip they use the ‘paid arrival’ system. This consists of travelling on credit with, on arrival, the price of the journey being paid by a family member who will subsequently be repaid by the migrant. The existence of small communities of people from Hombori in the coastal cities—Abidjan in particular—and also in Mali in Bamako and other cities plays an important role in the search for housing and work. Thus people from the village of Kelmi who have settled in Abidjan contribute to renting a house in the Treichville district for housing young people from the village who come to work in the large Ivorian city. The strong presence of people from Hombori in numerous sectors—carrying goods, looking after and selling cattle, caretaking, small retailing and domestic jobs for young women—makes it easier for new arrivals to settle in. Young unmarried migrants often share the same housing to keep expenditure on rent and food to a minimum, to be able to help their families and to save for personal projects.

Processes of individual affirmation and the diversification of work

Migration is not merely the result of adaptation or survival strategies in the face of acute problems of subsistence. It makes it possible to accumulate resources—at least migrants have this hope—to improve their financial and social positions. Implementing these proactive strategies is enhanced by the opening up of the district to the outside, with a surfaced road since 1986 and the spread of mobile telephones.

A large proportion of migration income is devoted to strategies aimed at gaining autonomy. The stay in another place for young unmarried people means that they escape from the supervision of the elders and earn personal incomes. The migration of young bachelors is an important stage for gaining experience and new skills, especially before marriage. Migration periods have enhanced the learning of new trades: tailor, radio repair, well-sinking and cattle dealer. Experience gained while away and small savings from migration are resources that are useful for increasing herds or starting other activities. For example, when they returned to the village, several former migrants in Kelmi have used the skills they had gained in Burkina Faso and Ivory Coast in the herding, trade and maintenance of cattle to start a cattle trade operation between Hombori, Bamako and Burkina Faso. In spite of the uncertainty of agricultural production, a few migrants seek to strengthen farm production capacity. In Dogon farms, the funds contributed by migrants have enhanced the spread of draught cultivation and the diversification of production.

A large proportion and sometimes all the money earned by young migrants is used for paying a dowry, which must be done before marriage. Marrying means gaining the status of a man on becoming adult. The rest is used for purchasing consumer goods (clothes, mobile telephone, etc.) that are the mark of modernity, of joining transnational culture and urbanity that enable them to stand out in the community.

Djougou: diversified farm production but precarious groups in a position of inferiority

Djougou is an administrative district with a Sudan-Guinean climate in the centre-north of Benin, peopled principally by Yom farmers and numerous minorities. Fairly varied food crops (yam, maize, sorghum, cassava, etc.) make it possible to feed a greater proportion of the population of 180,000. Nevertheless 10% of households are faced with food insecurity and disparities are marked. Malnutrition of 30% of the children in the district causes retarded growth (Droy *et al.*, 2014). Although rainfall is decreasing, it is still high at an average of 1,200 to 1,300 mm per year. But the availability of crop farming and pastoral resources is decreasing as a result of the continued increase in rural density. This climbed from 34 to 68 persons per km^2 from 1992 to 2013 and some areas are close to saturation. The increase in density is the result of natural population growth and the arrival of Bétaramibé (or Ditamari) and Lokpa farmers from the north and the west and Peul graziers from northern Nigeria, Niger and the province of Borgou attracted by relative availability of crop and pastoral resources in some zones. Within the district, landholding modes in rural areas strongly feature dominant lineages of Yom farmers and reduce access to crop and livestock farming resources for groups in inferior positions: immigrant farmers and the various groups of breeders. Seasonal and temporary migration of young men and women to countries near Benin (Nigeria, Niger) or to cities in Benin is very frequent in households with limited means. Those involved often see it as a way of escaping poverty, earning a personal income and obtaining resources that improve their situation in their home setting.

Semi-captive labour on farms in Nigeria

Many young Yom, Bariba and Peuls leave to work on farms in Nigeria at the frontier with Benin. This is not new migration but its organisation is changing (IMOROU *et al.*, 2011). Previously, heads of families handled the organisation of the migration of their children in order to have the labour needed for farm work and to hope for a little money when they came back. An increasing number of young men now leave without the knowledge of their parents, depriving the latter of labour that they do not have to pay. In addition, parents consider that their children run great risks because of the dangerous life and hard working conditions in Nigeria.

Most of the young men are recruited by intermediaries called *oga* or *waga*[2] (big brother and/or boss in Yoruba), who handle transport and accommodation on arrival in Nigeria and agree with the employers (without consulting the young men) with regard to the amount and procedure of payment. These middlemen are often former migrants who have gone into the fairly lucrative business of transporting and placing young men. From 2009 to 2013 in Gaounga, a Bariba village, a former migrant who set up as a mason after his third stay as a labourer in Nigeria, placed 48 young men from his village at farms in Nigeria. The *oga* have acquired social capital, and then profit from this to find work for young men who do not know anybody in the migration zone. When the latter have already spent a stay in Nigeria they do not necessarily call on a middleman. They prefer to come to an agreement about their pay directly with the farmers. But many of those who leave for the first time with lack of experience and contacts run greater risks than if they had used a middleman. This is why many of them use the services of the latter.

Many of the young men are employed by Yom and Bariba farmers who have lived in Nigeria for several years and are often sharecroppers (IMOROU *et al.*, 2011). Work is intense and labourers are obliged to complete the work given within the time allotted and must work six days a week. They start work in the fields at 7 am and, if the field is remote, must leave at 5.30 am. Depending on the case, work in the afternoon continues until 7 pm. The work to be done is all manual (earthing up, clearing and hoeing) and requires a great deal of physical effort. The employer houses and feeds the workers along with others who may come from other parts of Benin or from other countries (Togo and Burkina Faso). During their only day off in the week many work

2. The spelling of the name of these intermediaries varies according to the source: in Djougou, it is *waga* and *oga* is used in a report on juvenile migration (IMOROU *et al.*, 2011).

for other employers in order to earn a little pocket money for everyday expenses. If this extra work is well paid, some labourers leave the operations that hired them and work for the other employers.

Forms of capitalisation for returning home: a motorcycle and knowledge

Workers pay is fixed with no written contract by the *oga* and the employer. The amount is set according to the duration of recruitment and may vary according to the amount of work done by the labourer. The employees are not paid until the end of the recruitment period that varies from six months to often a year, two years and sometimes three. This system of payment at the end of the work is not new. It existed in francophone countries during the colonial period and was used to make an unstable or even 'irresponsible' work force in place until the end of works (VITI, 2013). Seasonal workers employed for six months in coffee and cacao plantations in Ivory Coast were often paid in this way. The system made it possible to keep young workers under control, to avoid the use of money earned on things considered as futile (being in fashion, entertainment and seducing girls) and also allowed certain employers to cheat their employees. Many young men in Djougou leave for Nigeria for the first time when they are 15 to 17 years old. They prefer to be paid at the end of the contract so as not to spend their earnings as they go along and for this forced saving to contribute their plans for when they return home. Indeed, after two or three contracts in Nigeria most of them return to their home region and set up an independent activity and found a family.

The sum is not generally handed over in cash but in the form of a motorcycle. In this case, a small sum is also given to the worker to cover his expenses during his return to Benin (petrol, clothes). A former migrant from the hamlet of Angara returned with a motorcycle and CFAF100,000 after working for the same employer for two years. In the village of Gaounga, a former Bariba migrant who has been an *oga* for several years got a motorcycle after a ten-month employment. The value of the motorcycle depends on what was agreed between the employer and the middleman when the worker is taken on. A new Chinese motorcycle costs about CFAF550,000 and the price of second-hand models varies from CFAF150,000 to 350,000. The middleman generally handles the purchase of the motorcycle.

The fact that most remuneration is based on obtaining a motorcycle at the end of the contract or that the young men sometimes take home other goods rather than money is explained by the low value of Nigerian currency, the naira, against the West African CFA franc. Bringing back goods is more profitable than changing nairas into CFA francs.

Failure to respect oral contracts is frequent, especially with regard to undertakings concerning payment of the worker. This failure can be by employers or *ogas*. *Ogas* are often blamed because they pay the young men; when the latter go back home without a motorcycle or with a motorcycle worth less than agreed, they tell their parents. It is often the latter that take action against the *ogas* and, if necessary, summon them before the local authorities (custom chief, gendarmerie, court) to force them to pay what they owe.

In most cases, on return the migrants sell the motorcycles they brought with them. The sums paid are used in several ways: helping the family (equipment for the house, help for the schooling of younger brothers and sisters), building and equipping their own dwelling and marriage expenses. The three types of expenditure show that there is a compromise between family approaches and individuality and matrimonial strategies.

The results of experience gained elsewhere are less visible but sometimes fundamental and contribute to spreading innovations and equipment, both agricultural (new methods for growing yams, growing watermelons, mills) and non-agricultural (video apparatus, television, generators, etc.).

Young men often have three or four stays lasting nearly a year in Nigeria, returning home for several months between each one. They then settle in their home village or elsewhere in the district of Djougou, raise a family and do their own work there. Most of the young people who leave want to return home. There are more opportunities for sustainable activity than in Nigeria where working conditions are hard. They maintain very strong links with their families and the aid that they provide on their return contributes to strengthening their position.

Nevertheless, a few migrants remain in Nigeria, especially when they had conflicts or problems—especially with the law—in their home community and may face difficulties if they return.

Female migrations for domestic service or work in informal micro-enterprises

Female migration to towns in other regions of Benin and in neighbouring countries, especially in Nigeria and more rarely in Niger, is also substantial in the district of Djougou. It involves girls who are sometimes very young—13 to 20-year-olds—and also married women who have children. This migration is substantial in poor households and in those where the head of the household does not perform his obligations because he is polygamous or often absent (Droy *et al.*, *op. cit.*).

The reasons for this temporary migration are linked to several factors. For the youngest girls from poor households it takes the form of temporary “confiages” of better-off families in order to reduce family expenses and receive a little money in return. Some are placed with apprentice mistresses (hairdressing, sewing, etc.). The others leave to save a little money and are recruited by micro-enterprises run by women (processing foodstuffs, street food), in family shops or in households as domestic servants. Their departure may also result from strategies to avoid the husband who is planned for them.

They leave with the hope of assembling a small capital for a wedding trousseau (cooking utensils, pagnes, etc.) and also to start a business activity on their return and not depend on their husband, or to maintain their rank in the household by making their contribution. Married women also leave, sometimes without their husband’s knowledge, to assemble a little money and start a business. The procedures for the organisation of female migration depend on several factors: age, the reasons for departure and contacts in immigration zones. As for young men, former female migrants act as intermediaries and handle the transport and recruitment of young girls or women by employers in Nigeria. Less frequently, people known by the parents of a girl who have contacts elsewhere offer help in finding a job.

In African towns, demand for female labour is strong for domestic work and in small shops and micro-enterprises handling services and processing. The working day is often long, starting at 5 or 6 am and lasting until late in the evening, but the rhythm depends on the personality and choice of the employer.

Pay is often fairly modest. For example, two Sew Sewga village women employed as cooks by female restaurant owners, one in Niamey and the other in Kandi, were paid CFAF7,000 and CFAF5,000 per month respectively. They were fed and housed by the women that they worked for, as is common for this type of job. Those who go to Nigeria seem to be able to earn a little more, especially when they receive daily payment that can range from CFAF 1,000 to 2,000, according to the reports collected. Like those for young men, agreements concerning remuneration are not always respected by employers and middlemen.

When young women have set aside savings and gained a certain know-how that enables them to go into business and buy a few goods (clothes and kitchen utensils), they marry and cease migration. Having children limits scope for working elsewhere. But mediocre household conditions (a husband who has abdicated his responsibilities or has no resources, polygamy, poor harvests, not enough land, etc.) may oblige them to migrate again. Some of those who go to Nigeria stay on and marry compatriots who have settled there.

The goods brought back (clothes and kitchen utensils), their appearance shown off on by their clothes and possibly a stoutness indicate success elsewhere, increasing the status of those who marry and encouraging other girls to leave.

The businesses that the young women start on return frees them from male supervision but keeps them close to the other work of the family (neighbourhood shops, manufacture of shea butter, etc.). These non-agricultural or peri-agricultural activities are more profitable than the work they did on the farm (in very small fields). Their earnings contribute to the family incomes and cover outlay on health, clothes and schooling for the children. The economic autonomy of women is sometimes fairly strong as some lend money to their husbands.

Differences and similarities between temporary migration in Hombori and Djougou

In Hombori, as in a large proportion of the Sahel, because of the ecological and climatic conditions, movement and mobility within a large area have long contributed to the maintaining of family farms (MOUNKAILA, *op. cit.*). Their long history and scale are explained by the fact that there is little work during the long dry season and by insufficient rainfall and the damage caused by various pests (caterpillars, crickets and seed-eating birds). While before 1970 the great majority of migrants consisted of young men, the profiles of migrants have changed since the droughts and food crises of the 1970s and 1980s. Droughts and migration have caused the emergence of new economic patterns that have remained.

Temporary migration usually just lasts for the dry season. However, since the 1970s, climate disturbances and the frequency of attacks by pests have obliged many migrants to leave earlier and return later. The fact that migration goes far back and is large in Hombori is also explained by the rigidity of the social structures in the region, as in western Niger and northern Mali. In societies whose hierarchy is based on the status inherited at birth, migration since the colonial period has given an opportunity to low-status groups—Banney, Rimaibé and Bellah—to escape the domination of their former Songhai, Peul and Tuareg masters and improve their conditions of life.

As a result of the agricultural potential in the district of Djougou, migration to elsewhere is not as longstanding as that from Hombori and its scale remained modest for a long time. It has increased since the 1980s mainly as a result of increasing population density against a background of landholding inequality. In the old, densely populated areas, young people and women were the first to be affected by the increase in disparities and tension in access to land. But until the early 1990s, settling remained easy in the parts of the commune where density was lowest. The rapid population growth everywhere in Djougou reduced opportunities for young farmers who wished to establish their own farms (BIDOU and DROY, 2012). The most vulnerable households are those of immigrant farmers with no land rights, poor native farmers and Peuls with no cattle—and especially families with numerous children in which expenses for the workers are high. These groups make the largest contribution to migration flows.

Many young men in Djougou, more so than in Hombori, are tempted to leave and work elsewhere as the tasks that they perform on family farms are not paid, they benefit little for the income from the sale of production and the farm chiefs are reluctant to give them a piece of land that they can operate for themselves.

The features of migration from Djougou are different to those of Hombori. The calendar is not linked to the seasonal features of farm work. The young men who go to Nigeria leave to work on farms for comparatively long continuous periods of one to two years. Unlike most of the young men from Hombori, they do not return to the village to participate in agricultural work.

Djougou is one of the regions in Benin where child trafficking is substantial and where many children are entrusted to or placed in households against a modest amount of money. Migration often concerns younger children than in Hombori. The dividing line between migration and 'placement' is difficult to define; young people are taken over by networks that exploit child labour, but they do not leave against their will. Because of the precariousness of family situations and parents' failure to take them in hand, mobility is seen by many boys and girls as the main opportunity to overcome poverty, find resources for projects and for affirmation in their home environment. In families with limited resources, work at an early age (often 6 or 7 for both sexes) prepares young people to affront exhausting work conditions elsewhere.

As women have greater financial independence in Djougou, female migration is greater than in Hombori. The migration of young girls and women is much better accepted than in Hombori. In the latter district, although an increasing number of Dogon girls and those of servile extraction leave to work as domestic staff elsewhere, female migration mainly concerns women who accompany their husbands or go to join them.

Likewise, migration shifts and the movements of migrants do not display the same features. In Djougou, the role of the *ogas* in the organisation of juvenile migration is determinant and particularly ambiguous. Most are former migrants who profit from their contact capabilities in the departure and arrival zones to make money by handling the transport of young people to immigration zones, making them work for them and placing them with employers, establishing agreements with the latter covering the type and amount of payment and handling the awarding of this. In Hombori, the migration of young people is less strongly supervised and they have more freedom of choice as regards activities, working conditions, payment and destination. Nevertheless, their migration is facilitated by people from Hombori settled in the immigration destinations and who help to cover transport, provide accommodation and help migrants to find work.

As a result of the crises that affected the former migration destinations, and especially the coastal towns where people form Hombori used to find work, migration is becoming focused on Mali and in nearby regions in Burkina Faso and Niger. However, opportunities for work and pay are often limited, tending to reduce the resources acquired. The migrants who succeed are those whose skills allow them to move about in mainly Sahelian areas.

Djougou is close to Nigeria and this provides many opportunities. The demand for labour in commercial farming is high thanks to strong urbanisation and an increase in demand for foodstuffs, stimulating the development of agricultural production. Women and girls find work easily in small service activities in towns. The urban fabric is denser in Benin than in Mali and there are more possibilities for work for girls from Djougou. The town of Djougou with a population of 80,000 and the secondary urban centres form a district with a fairly dynamic economy providing more scope for employing young migrants when they return. In Hombori, the already modest potential decreased markedly after the crisis and the conflicts that affected northern Mali.

The working conditions of most migrants from both Hombori and Djougou are very difficult because of the features of work in the informal sector and in farming. But the strong supervision of workers is a greater constraint for young people from Djougou.

The purposes of migration differ in some respects. In Hombori, resources gained through migration are used mainly to reduce food insecurity. In most cases the investments made by migrants are not devoted to strengthening farms, as agriculture is an uncertain activity. In contrast, they are aimed at diversifying activities to improve family resources. This diversification often involves the development of small-scale livestock farming and trade in cattle, enhanced by increasing demand for animal products in towns in Mali and the neighbouring countries.

In Djougou, in contrast with Hombori, rainfall does not seem to have had much impact on migration. In Hombori in 1970-1980 and even more recently in years with poor rainfall, the more numerous departures took the form of survival migration. The link between migration and reducing food insecurity is very limited in Djougou. The money earned by migrants is used partially for schooling brothers and sisters, to cover health expenditure, clothing, family ceremonies, etc. Earnings of migrants are also used in both places to set up non-agricultural activities. In Djougou, the migration resources of young women are used to a considerable degree to strengthen their non-farm activities. The increase in demand for services in villages—which are modernising rapidly in Djougou—and the modernisation of housing favour the development of new trades.

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Chapter 14

Seasonal migration and climate change in rural Senegal

A form of adaptation or failure to adapt?

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Introduction

Human migration resulting from climatic and environmental change is not a new phenomenon. Populations have migrated for centuries, often seasonally, following changes in their environment. It is even a principle of life for nomadic and pastoral peoples who continuously seek new resources. However, the question of relations between migration and the environment has only become a subject for scientific debate very recently, for the first time in the 1980s with the major ecological crisis triggered by the great droughts in the Sahel and for the second time with the emergence of the paradigm of climate change in the 1990s.

All authors agree that the droughts of 1968-1974 and 1982-1985 caused increased migration in Niger, Mali, Senegal and Burkina Faso both immediately and in the long-term (COULIBALY and VAUGELADE, 1981; FAULKINGHAM and THORBAHN, 1975; FINDLEY, 1994; GERVAIS, 1987; HENRY *et al.*, 2004). Use of this adaptation strategy is all the more systematic when drought is combined with rapid population growth and increased poverty (Henry *et al.*, 2004; KNERR, 2004; PEDERSEN, 1995; TAMONDONG-HELIN and HELIN, 1991). Generally, these authors note that intercontinental migration (to France) does not have the features of a spontaneous response to the ecological crisis, in contrast with internal or cross-border and circular or short-term migrations that more than doubled during the droughts (FINDLEY, 1994). Finally, they observe that migration caused by the droughts affected mostly the poorest families and young women and children, many of whom are put in foster care.

The question gained global status in the early 1990s when the international community started to recognise the global challenge of climate change, together with its links and impacts on human mobility. The debate then focused on theoretical views of environmental migration. The first approach that tended to dominate the debate was based on conventional push-pull theories. Environmental changes in poor countries classically result from demographic pressure on natural resources that exceeds the carrying capacity of an area's resources, thus causing a population exodus. This approach inspired by Neo-Malthusianism thus provides a mechanical and encompassing 'naturalising' explanation in which migration results from population growth that exceeds the limits of natural resources. Environmental migration is therefore the *escape* from a close threat, the *abandoning* of the home environment that has become inhospitable and the *failure* of persons and systems to self-adapt. This current of thought therefore sees it as forced displacement driven essentially by the environmental factor. Reflecting this trend, some studies on the poorest countries describe rural-urban migration as the final response to the difficulties facing rural households that cannot adapt to landholding pressure, state's withdrawal from agricultural sectors (MORTIMORE and TIFFEN, 2004) and environmental degradation.

In contrast, the other migration theories that include the 'new economics of labour migration', the structuralist approach, the social network theory and the transnationalism theory all suggest in their own way that environmental migration is not only a response to a strong stimulus from the natural environment but is also migration per se with complex causality and a decision process, and that it should not therefore be analysed as totally different to other migration. People rarely move under the constraint of a single factor, except perhaps in the case of major natural catastrophes.

Even though migration by rural populations occurs more often when annual rainfall is insufficient and households no longer have food security, it is also related to a collective strategy defined at farm level (STARK, 1980). These analyses consider that the relationship between environmental change and migration is dynamic and complex, and does not just concern contextual (macro) but also individual- (micro) and farm-level (meso) factors. Like any other kind of migration, environmental migration is thus a socially constructed phenomenon and a choice in competition with many other adaptation options (HENRY *et al.*, 2003).

Whether it is a survival strategy or an opportunity to improve living conditions, migration does not necessarily mean breaking with or abandoning the source territory, even if the causes are environmental. Rural-urban migration is usually analysed in relation with the sending area. Studies on West Africa show that population movements are generally temporary and/or circular labour migration (BEAUCHEMIN and BOCQUIER, 2004; HAMPSHIRE, 2002; KONSEIGA, 2007). Migrants maintain links with their home village and participate actively in food security and sometimes in the development of their community's agricultural or non-farming activities.

Migration may then be a short-term survival strategy aimed at meeting livelihood needs of households left behind through remittances used for consumption or by relieving the strain on food because consumers have left (DE HAAS, 2008).

Migration may also be an opportunity in which collective and individual strategies are mingled and enhance individual and community lives (Harbison, 1981; Katz and Stark, 1986; Root and De Jong, 1991; Stark and Levhari, 1982). The household's migration history and family ties with urban residents reduce the economic and emotional cost of migration and therefore strengthen individual motivation and facilitate migration (Root and De Jong, 1991). Thus the households with the most human capital and urban social networks are those that involve in migration most easily and strongly.

Assessing migration in terms of success or failure is a complex process that calls for taking into account the migration project, the migrant's previous migration experience and the contexts of departure and return (Cassarino, 2004; Cerase, 1974). It is also dynamic insofar as a migrant's project is ceaselessly reformulated according to the failures and successes experienced. Nevertheless, in the same way that neoclassic economic theories affirm that any return from migration shows the inability of the migrant to maximise the income expected at his destination (Todaro, 1969), the supporters of a 'maximalist approach' (Suhrke, 1994) to the theory of repulsion/attraction factors consider that out-migration for environmental reasons often express the failure of individuals and groups to adapt to the environmental change facing areas from which these migrants originate (Myers, 1993, 2002; Myers and Kent, 1995). The term 'refugee' is indeed used readily and this does not indicate an adaptation strategy.

Although it results partially from environmental causes, seasonal migration is difficult to analyse in terms of failure alone. Many studies carried out on this issue in Africa have shown that this form of mobility often follows a collective rationale whose aim is to maintain farms in spite of the constraints that they face and give them the technical and financial resources to enable them to develop further.

The Niakhar Health and Demographic Surveillance System (HDSS) site in Senegal provides an interesting opportunity for examining the relationship between internal migration and slow environmental and climatic changes (excluding sudden natural disasters) over a long period. Observations have been recorded there for more than 50 years and provide information about migration trends and its intensity, forms and causes. The Niakhar HDSS has also recorded daily precipitation totals since 1982 and, by means of several surveys, has documented the agricultural performance and food security of farms for about a decade.

From the economic point of view, agriculture in the Niakhar HDSS site, consisting of 30 villages, is focused mainly on rainfed millet and groundnut. After a dry period lasting for nearly three decades (1970-1999), rainfall totals have increased since the 2000s and there has been an uptrend in particular between August and mid-September (Salack *et al.*, 2011). We observe at the same time a growing diversity of farm strategies and varying performance. First, we examine whether circular labour migration is sensitive to recent changes in rainfall and its strong variability given this new context. We then assess the impact of this migration on the cereal self-sufficiency of households, especially for poor harvest years. Finally, if seasonal migration proves to be a response to climatic events, we show that not all farms use this adjustment lever to the same degree. Overall, the extensive resort to seasonal labour migration might depend on the occurrence of dry years and the acute vulnerability of some farms unable to cope with the resulting food crisis.

Context of the study

The study area covers the northern part of the former Sine Serer kingdom in the Fatick administrative region (BECKER, 2014; BECKER and MBODJ, 1999). It is located in a semi-arid dry zone (annual average rainfall between 500 and 650 mm per year since the mid-2000s), in the south-west of the groundnut area. The economy of the study zone is centred on agriculture and dominated by millet for on-farm consumption and groundnut as a cash crop, together with livestock (cattle, sheep and goats). This ancient farming system is set in wooded grassland in which man has chosen every species for its usefulness. Acacia (*Faidherbia albida*) is the dominant species, providing forage, food and ligneous resources and, together with livestock farming, ensures the maintenance of soil fertility.

The study zone covers all 30 villages of the Niakhar Health and Demographic Surveillance System (Niakhar HDSS)—a study population of about 45,000 in 2013 and an area of 200 sq. km. Average population density is 215 persons per sq. km, with villages reaching or exceeding a density of close to or greater than 400 persons per sq. km (DELAUNAY *et al.*, 2013 a). Despite signs of fertility transition onset, the fertility rate in the Niakhar study area is still very high (DELAUNAY and BECKER, 2000; DELAUNAY *et al.*, 2003) and remains the driving force of population growth. Fertility still exceeds six children per woman (BUIATTI *et al.*, forthcoming). Mass schooling is recent and still has a weak effect on fertility behaviour. In contrast, mortality has sharply decreased since the 1960s. Life expectancy has increased from 30 years in 1962-1968 to 69 in 2009-2011. Natural growth is therefore very strong at 3.5%.

Over the past century, the public authorities and population have tried to reduce the anthropic burden on the area and its resources by means of permanent and temporary internal migration. In the 1930s, the colonial authorities considered that population density was very high in the Sine region (DUBOIS, 1975). Furthermore, the authorities regarded the Serer from Sine and Saloum as excellent farmers capable of growing groundnut in the pioneer land in eastern Senegal. The first controlled emigration movement was thus set up, in particular to the Kaffrine region where the colonial administration awarded uncultivated land to farmers (GARENNE and LOMBARD, 1991). This population settlement policy was used and implemented on a larger scale after independence in the Third 4-Year Plan (1969-1973). The Senegalese authorities encouraged the shifting of several thousand Serer families from 1972 to 1980. First directed and then spontaneous, these population flows were nonetheless not as intense as expected (in 1976, 5.3% of the families in the Niakhar district left to colonise pioneer fronts in the '*Terres neuves*' (New Lands) of eastern Senegal from 1972 to 1987). Furthermore, even though they contributed to freeing some land, there was only a small decrease in the overcrowding of the area and a pause in demographic growth that lasted for only 5 years (Garenne and Lombard, 1991). These migration movements were accompanied after the Second World War by the first voluntary departures to large towns, often by way of stages such as Fatick, Kaolack or Thiès (Becker *et al.*, 1987; Becker and Mbodj, 1999).

Seasonal labour migration to the cities by young men and women started in the 1960s. They concerned the villages close to road links and mainly households belonging to castes (griots, blacksmiths, etc.) (Guigou, 1999). Young people left for several months of the year outside the farming period in order to find paid jobs (Roch, 1975). Seasonal migration spread to all the villages in the surveillance site in the 1970s and 1980s, and started at the onset of the dry season. This was also the period when migrant networks settled in the main destination cities (Fall, 1991). The Senegalese state withdrew from the groundnut sector in the 1990s and 2000s under pressure from the structural adjustment programmes imposed by the Bretton Woods institutions (Adjamagbo and Delaunay, 1998; Mortimore and Tiffen, 2004). The halting of subsidies for seed, inputs and groundnut purchase prices from farmers considerably weakened the role played by this crop in the local economy. The groundnut belt thus had to face a serious agricultural crisis that forced farmers to make agricultural innovations and diversify their incomes. This was when seasonal migration became widespread and reached a considerable scale, affecting very young people, especially girls (Becker and Mbodj, 1999; Delaunay, 1994; Delaunay and Enel, 2009; Delaunay and Waïtzenegger Lalou, 1998). In spite of a diversification of profiles and reasons for migration, the role of food vulnerability is still important today (Chung and Guénard, 2013).

With worsening climatic conditions, the liberalisation of the groundnut sector and the resulting agricultural crisis, the migration phenomenon gradually spread to all villages, all social groups and all age groups. It intensified in parallel with the improvement of transport (Lombard and Seck, 2008) and evolved in both form (destinations, characteristics of migrants) and duration. Depending on the strategies of households, migrants thus became an adjustment factor (a subsistence strategy) or an actor in social and economic change (enrichment strategy).

Dry season migrations referred to as *norane* seasonal migrations form the largest category and involve mainly young people going to cities. The men are very often unmarried and seek a job in town to help the family, prepare their marriage or cover their personal needs. Girls generally profit from migration to cities to earn money for a trousseau for their weddings (Delaunay, 1994; Delaunay and Enel, 2009). Both girls and boys return for the farming season. In the rainy season, young men may leave to work (*navetane*) as farm labourers or shepherds in rural areas. This *navetane* seasonal migration is less frequent than the *norane* one and generally occurs when a farm has surplus agricultural labour. Finally, in addition to these seasonal movements governed by the farming calendar, a mainly female form of migration has developed since the early 2000s with the generalised increase in schooling and is governed by school holidays. This migration enables them to cover school expenses and new needs (clothes, cosmetics, telephones, etc.) (Moullet and Engeli, 2013).

Material and methods

The Niakhar HDSS is the oldest population observatory in Africa. The first demographic observations were performed in Niakhar district in 1962 by Pierre Cantrelle, physician and demographer, and were aimed at measuring child mortality and collecting civil status data (CANTRELLE, 1965 a, 1965 c). Repeated surveys were implemented and the study area rapidly became a multidisciplinary research platform hosting many research projects in different fields such as demography, medicine, geography, agronomy and sociology.

The Niakhar HDSS follow-up was set up in its present form in 1983. It provides longitudinal data, gathered continuously, on all the residents of the 30 villages. An update round is run several times a year to record all the events that have taken place (pregnancies, births, marriages, deaths, weaning, migration, etc.) since the previous survey. Arrivals and departures of individual persons are recorded in detail, with special attention paid to seasonal migration from 1998 onwards. Thus in each round, absent persons are identified and household members are questioned about absence motives, and migrant destination areas and activities.

Specific surveys are also carried out periodically between two update rounds. They are focused mainly on schooling, household equipment, housing quality and agricultural production. The '*Biens et équipements'* survey (Goods and equipment) was thus run in all households in 1998, 2003 and 2014. It makes it possible in particular to measure the patrimonial and multidimensional poverty of households and to make an inventory of the farming equipment owned by holdings. A '*Cultures et élevage'* survey (Crops and livestock) was conducted from 1998 to 2003 to evaluate yields, the degree of food self-sufficiency and the role of migration in household strategies. Finally, the Niakhar HDSS facilitates the conducting of one-off operations such as the '*ESCAPE-Senegal*' survey ("Environmental and Social Changes in Africa: Past, present and future") in 2013-14. This survey was based on a random sample of 1,061 family farms (32% of the households monitored). A 'Household' questionnaire submitted to farm-household heads was used to describe the cropping system used during the 2013 rainy season. It also documented the economic status of the household, non-farming activities and the sociocultural characteristics of the head of household. An 'Individual questionnaire' was then given to a household farmer who had cultivated at least one field during the three years preceding the survey. This questionnaire was focused on certain cash crops such as groundnut and watermelon and on cattle fattening.

Definitions and measurements of migration

The measurement of population mobility is complex even when reliable, accurate data are available. At the individual level, there are different kinds of movements according to destination, duration and reason. To quantitatively measure migration, there is a need to establish precise criteria on whether the movement should be considered as migration or a simple journey.

The residency status within the HDSS site depends on duration of stay and motivations. Residents stayed away from the HDSS site for more than six months are considered as out-migrants and exit the study population. However, here are several exceptions, such as young people who leave to gain an education (but who return for at least a month during the holidays), seasonal workers (who return for at least one month a year) and labour migrants who remain family heads (DELAUNAY *et al.*, 2013 b). Likewise, people that move in the study site become immigrants after the threshold period of six months or when they have declared their intent to stay. In other cases, they are considered to be visiting or passing through.

Although absences were recorded in writing in field logs, they did not start to be entered in the database until 1998 onwards. Data on temporary migration is therefore included in the HDSS platform from that year onwards, with dates of absences and returns from migration, destinations and reasons.

Permanent migration consists of departures or arrivals that do not match the definitions of temporary migration and visits above. Emigration and immigration rates are defined by calculating the ratio of the number of migration events in a group (defined by age or sex) to the resident population in this group (person-year). These indicators show the proportion of migrants (emigrants and immigrants) in the resident population in a given year.

Seasonal labour migration can be measured in two ways. Like for permanent migration, we can calculate a migration rate by dividing the number of temporary labour migration departures by the number of residents. In addition to measuring the proportion of seasonal migrants, we calculated the intensity of seasonal migration. Instead of considering the persons who had been migrants and those subjected to this risk, we can take into account for a given year the durations of seasonal migrations as the numerator and the total time of exposure to the risk (person-years) experienced during this period by those who escaped seasonal migration as the denominator. This more accurate measurement gives an indicator that shows the true weight of migration in the population, allowing for the durations of presence and absence.

Farm classification method

Farms sometimes opt for seasonal migration, either to face certain constraints such as rainfall deficit or food insecurity, or to improve the standard of living of migrants and their home household. Seasonal migration was analysed for different types of farms in order to highlight these relationships.

A typology was drawn up using information available in the population database (the Niakhar HDSS) and in the '*Biens et équipements 2013*' and '*ESCAPE-Senegal 2013-14*' surveys. Distinction is usually made in the literature between two farm typology categories: a structural typology that consists of defining groups of farms according to their means of production and a functional typology in which farms are differentiated according to the strategies used to meet constraints. Given our aim to categorize farms according to their adaptation capacity and vulnerability, we combined both approaches within a single typology. This category system was developed in two stages.

First we defined a structural typology considering the farmer's agricultural resources (land, labour, equipment, draught animals). A first factorisation operation was performed using multiple correspondence analysis to reduce the volume of this information. This factorial plan was then used as the basis for the categorisation of farms by ascending hierarchical classification.

We then drew up a functional typology taking into account the farming strategies identified, the structural typology, the farming systems used on family farms, food consumption, and economic status and demographic features of the household. Overall, 40 variables were selected to define farm structures and their economic strategies.

Functional typology is more complex to construct than structural typology because of the non-linear relationships between the variables considered. Indeed, farmers' strategies vary according to the constraints to which the household is exposed and sometimes compete with each other. To take into account the complexity of the relationships between variables, we used a non-hierarchical, unsupervised classification method whose learning algorithm is better suited to structures of non-linear data. These are self-organising maps or Kohonen maps (1995) (after the name of their designer), a perfected version of the K-means (or dynamic clustering) method that can separate non-linear groups.

We obtained a total of four farm categories, defined as follows:

1– Very small farms with very little agricultural equipment, labour and land but strongly supported by non-farming activities. They form 27% of all farms in the HDSS site.

2– Farms displaying under-production. They have substantial land but weak investment capacity and a low level of equipment. Their labour is under-used. The category forms 19% of farms.

3– Large farms that provide household food security and focus to a great extent on marketing their agricultural production. They have substantial capacity for farmland development, investment and innovation. These form 25% of farms.

4– Medium-sized farms with fairly ample land and equipment resources but that do not ensure food security of their very large households and that have small investment capacity. They are overall in a situation of decapitalisation and their labour resources are used mainly in farming. This group forms 29% of farms in the HDSS site.

Population movements dominated by seasonal migration

Long-term migration

In combination with a residential change, population movements can either be long-term (more than a year) and sometimes permanent, or seasonal and therefore temporary. Movements in the first category are comparatively few and far between and fairly balanced as regards entries and exits in the study area. Emigration and immigration rates are around 50‰. These movements have tended to decrease during the period as a whole (Fig. 1). However, this pattern is doubtless partly an artefact resulting from the setting up in 1998 of procedures for monitoring temporary migration. From 1984 to 1998, the data collection system did not make it possible to distinguish clearly between seasonal and long-term migration. Some departures for more than six months and considered before 1998 as emigration, are now clearly recorded as temporary migration.

Although this indicator is sensitive to the change in the data collection rules, some conclusions can be drawn from it, especially after 1998. Immigration and emigration rates display a downward trend from 1998 to 2013—more marked for women (Fig. 1). During this period, net migration—the difference between arrivals and departures—was almost always negative (Fig. 2), very low and balanced between the sexes. *Since*

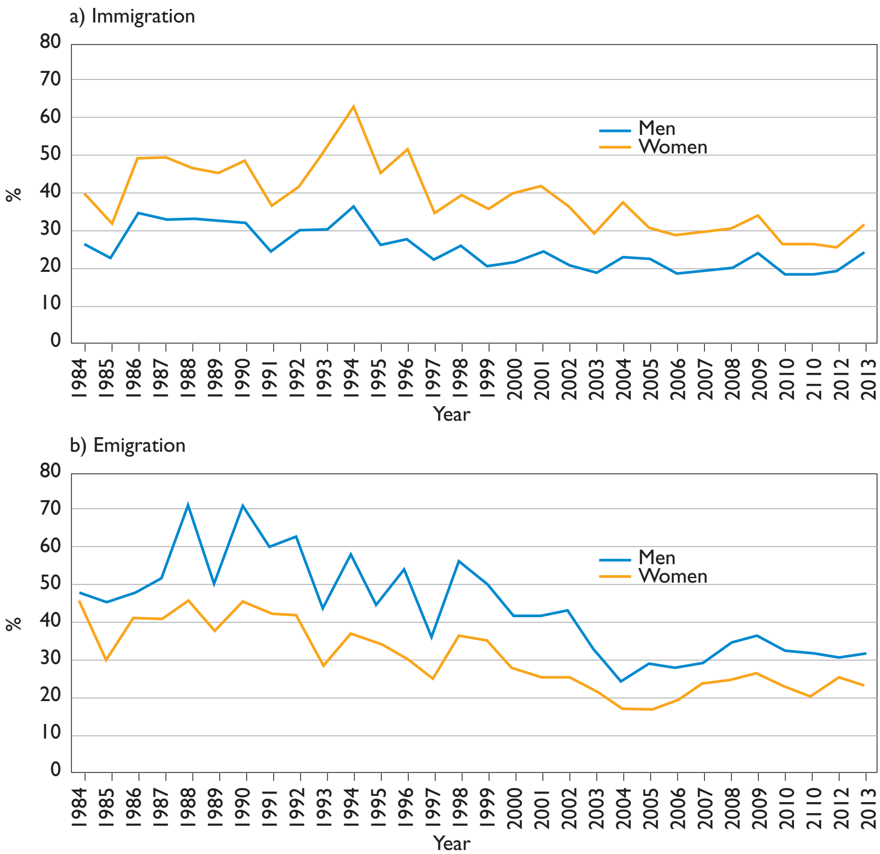

Figure 1.
Immigration rate (a) and emigration rate (b) (Niakhar HDSS site, 1984-2013).

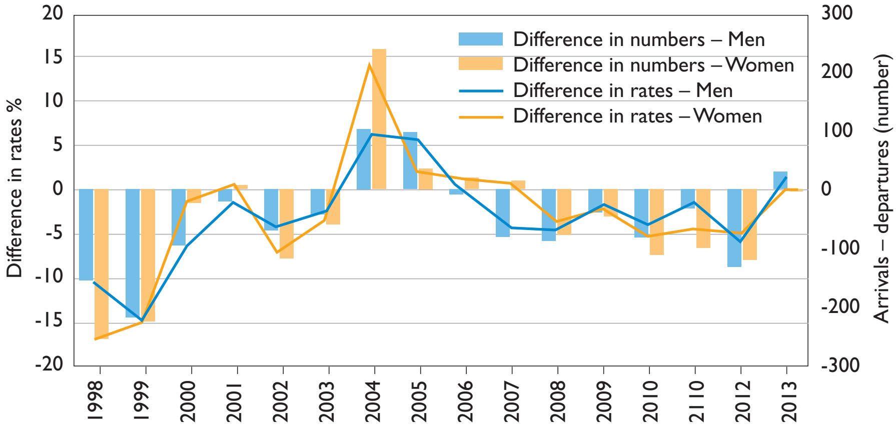

Figure 2.
Net migration in differences in rates (immigration rate – emigration rate) and numbers (arrivals – departures).
Niakhar HDSS site, 1998-2013.

1998, the Niakhar study zone has lost an average of 50 men and 50 women each year as a result of long-term migration. With such small numbers, permanent migration does not therefore seem to be an adjustment factor either as regards demographic pressure (with, nonetheless, a natural increase rate of more than 2.5% per year from 1994 to 2013) or as regards variations in rainfall (rainfall depth from 2002 to 2006 was distinctly less than after 2007).

Whether arriving in or leaving the Niakhar study area, women are more prone to permanent migration than men throughout the period (Fig. 1). Reasons for arrivals and departures by women are mainly related to marriage and divorce (Fig. 3) as

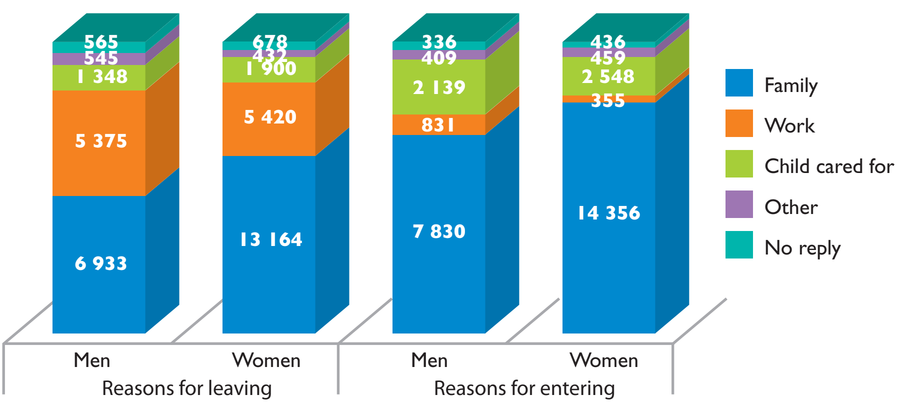

Figure 3.
Distribution (in numbers and %) of emigration and immigration according to sex and reason for migration.
Niakhar HDSS site, 1984-2013.

marriage determines the place in which a woman lives (virilocal marriage). On completion of the matrimonial process, the wife moves to her husband's home and returns to her parents' home after a divorce and even sometimes after the death of her husband. But work is nevertheless the second reason for emigration (accounting for 36% and 25% of male and female departures respectively) and, in numbers, involves women as much as men (- 5 420 compared to - 5 375 during the period). In contrast, work is rarely a reason for long-term immigration (7% for men and 2% for women).

Seasonal labour migration

As mentioned above, the intensity of seasonal migration can be measured by dividing the number of departures in temporary labour migration with the number of residents to obtain a migration rate (Fig. 4). On average since 1988, 30% of men and 20% of women are engaged in seasonal labour migration. In other words, one man in three and one women in five leave the HDSS site at least once a year to seek work. Seasonal mobility is therefore much greater than long-term migration that concerns an average of only one person in 20 (5%). It also affects more men than women (Fig. 4) but nonetheless displays an average migration duration of 4.7 months for both sexes. Expressed in terms of numbers, *seasonal movements since 1998 total 58,000 male migrations and 40,000 female migrations, that is to say respective averages of 3,600 and 2,500 circular migrations per year.*

Temporary labour migration in the Niakhar HDSS site probably started with the ecological shock of the 1970s, but then became widespread to the extent that today it is more or less an obligatory stage for young people in the Sine region. Among residents on 1 January 2014, 90% of men aged 30-34 and 70% of women aged 20-24 had already completed one temporary labour migration. As explained in detail

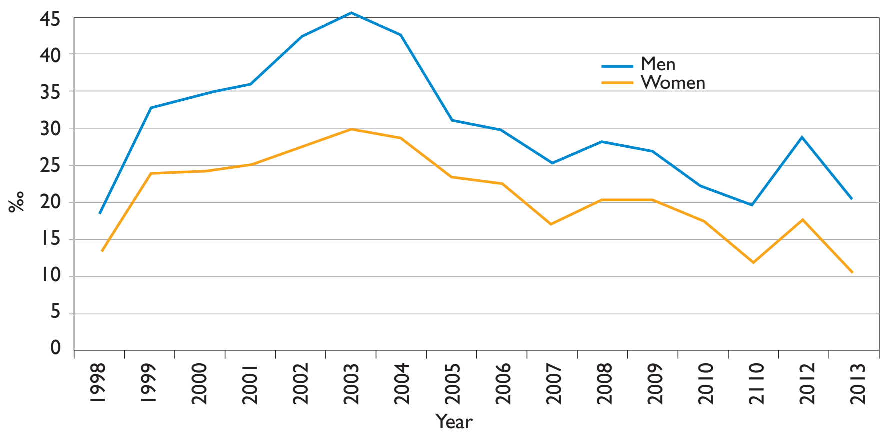

Figure 4.
Trends in seasonal labour migration.
Niakhar HDSS site, 1998-2013.

in the next section, the proportion of seasonal migrants is still sensitive to climatic events and the agricultural performances of the year; this is evidenced by the peak in male migration in 2003. The millet and groundnut harvests had been particularly disastrous in 2002 because of very serious rain shortage (less than 200 mm over the year). However, the migration system now responds to social and economic rationales—both individual- and household-related—that go beyond simple determinism driven by the climate and the environment. Ample rainfall and good harvests never cause the ceasing of migrant flows.

The migration rate calculated in this way awards equal weighting to each migration, whether it lasts for a week or for 11 months completed. We therefore chose to refine our calculation by taking the duration of migration stays into account. A person-year count was performed, that is to say the precise time spent in migration by each person during a period of a year. One person-year in migration corresponds to a cumulated 12 months of absence by one or more persons. This figure related to the number of residents in the HDSS site (also measured in person-years of residence) gives an indicator that reflects the real weight of persons absent from the households while taking the duration of absence into account.

Temporary labour migration has considerable weight in the population: 11% of the men and 8% of the women were absent because of labour migration. *In other words, 1 person in 10 is absent from the Niakhar study zone at any given moment for reasons of temporary labour migration.* The proportion varies during the period, showing the same major peak in 2003 with an average (in person-years) of nearly 15% absence for men and 11% for women (Fig. 5). Although seasonal labour migration intensified after the 2002 agricultural crisis, a decrease in intensity (in terms of duration of absence) is nonetheless observed since 2010 (Fig. 5). The dwindling of time

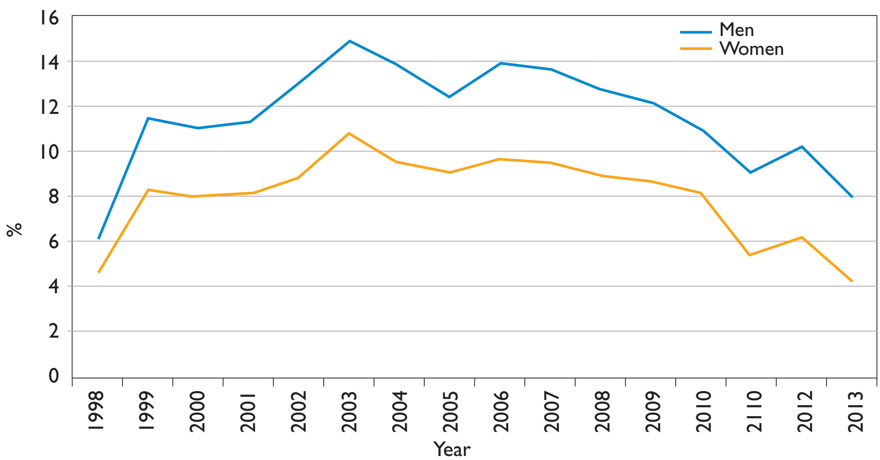

Figure 5.
Proportion of temporary labour migrants in person-years.
Niakhar HDSS site, 1998-2013.

of absence occurs a little later than the decrease in the number of migrations (Fig. 4), showing that the decrease in the number of persons migrating was compensated from 2005 to 2010 by a lengthening of durations of migration.

The spread of seasonal migration can be addressed using households with at least one temporary labour migrant during a given year. The proportions of such households were very high overall from 1998 to 2013, fluctuating around 70%, with an upward trend during the period. The figure even reached 80% from 2008. Increased use by families of labour migration led to a lengthening of periods of absence and the dissociation of migration from the farming calendar.

The average duration of absence from 1998 to 2005 was 3.9 months for men and 4.1 months for women. After 2005, the duration of absence by men increased by an average of 1.5 months and by 1.2 months by women. The forms and calendar of temporary labour migration are much the same today as those described in the past. From 1999 to 2012, whatever the month of the year, at least 400 persons left for seasonal migration (Fig. 6a). However, these population movements increased during the dry season (peak in January-February) and the rainy season (peak in June), showing the two usual migratory flows in Senegal: dry season migration (*norane migration*) and rainy season migration (*navétanat*) (PONTIÉ and LERICOLLAIS, 1999; ROQUET, 2008). Dry season migrations, the largest until recently, start after harvest. Migrants then generally go to cities to seek paid manual work (masons, carters, fishermen, etc.). Women work mainly in domestic service in Dakar and Mbour. The *navétanat* occurs at the beginning of field work when not all the abundant workforce can be used on family holdings. Men then leave home to work in places where there is insufficient agricultural labour (in the Saloum and eastern Senegal).

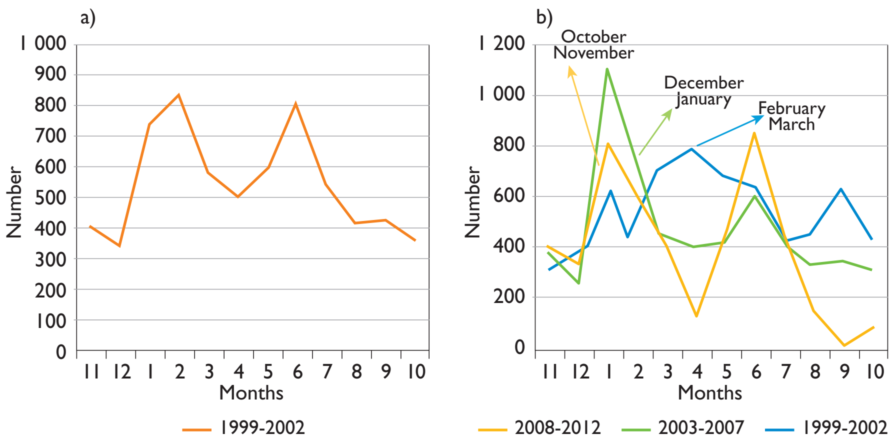

Figure 6.
The number of departures for temporary labour migration by month and period of departure. Niakhar HDSS site.
a: 1999-2012; b: three different periods: 1999-2002, 2003-2007 and 2008-2012.
Inset: the months of the celebration of Tabaski (Eid al-Adha) during each period.

This general model of seasonal migration has changed somewhat in recent years. Although the intensity and calendar of dry season migration is still governed by harvests (field work calendar and yields), it can be seen in Figure 6b that departures also tend to be adjusted according to the date of the Tabaski festival (Eid al-Adha) when this occurs on the usual dates for migration departures (start of the calendar year). A shift in time of peak departures can thus be seen from one period to another (Fig. 6b). Maximum dry season departures were recorded in March-April during the period 1999-2002, in February during the period 2003-2007 and in January during the last period, that is to say one to two months after the month of the Tabaski festival.

The other point is that rainy season migration has considerably expanded in recent years. Departures in May, June and July increased by nearly 30% from 2005 to 2010 (middle of the last two periods), making the onset of the 'rainy season' as important a time for seasonal migration departures as that of the beginning of the year (Fig. 6b). This situation must be caused partly by population growth. Household size doubled from 1984 to 2012, increasing from an average of 6.7 persons to 13 persons today, doubtless causing an increase in the labour force during the period of field work, which could find employment through migration. However, widespread schooling for children—especially girls—at primary and secondary levels is probably the factor that has done most to change the seasonality of migration in recent years. Today, 76% of 10-14-year-olds and 72% of 15-19-year-olds attend or have attended schools. The time spent in school means that most cannot migrate and have to postpone this until the holidays at the end of the school year.

As shown in Figure 7, this recent phenomenon mainly concerns girls. Unlike men, who migrate extensively at the beginning of the year, women and girls migrate more during the rainy season (2.5 times as many departures in June than the annual average),

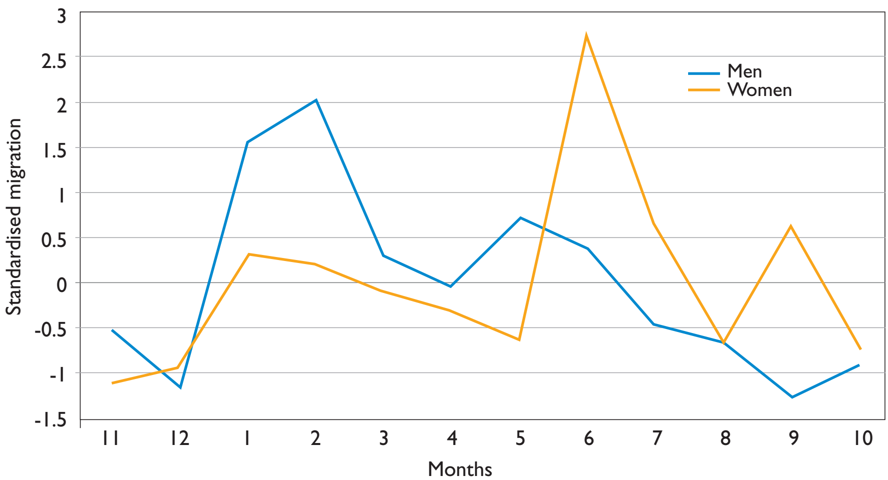

Figure 7.
Monthly variations (centred reduced variable) of temporary migration by sex.
Niakhar HDSS site, 1999-2012.

but most likely for a somewhat shorter length of time. This shortening of absences is probably caused by the fact that the proportion of migrants reaches 30-40% (in person-years) at 25-29 years old for men and 15-19 years old for women; migration of young girls (in duration of absence) decreased from 2008.

Seasonal migrations, climatic factors and food security

Temporary labour migration is by far the most dominant form of human mobility in the Niakhar HDSS site. The causes of these movements are mainly rainfall uncertainty (severe droughts in the 1970s and 1980s), its impact on performances in agriculture and pressure on land, which was prompted by population growth (GARENNE and LOMBARD, 1991; ROQUET, 2008). But with time and dissemination of the migration behaviour, population movements do not fully result today from their root causes, and migration networks has certainly led to expand this form of migration (FALL, 1991).

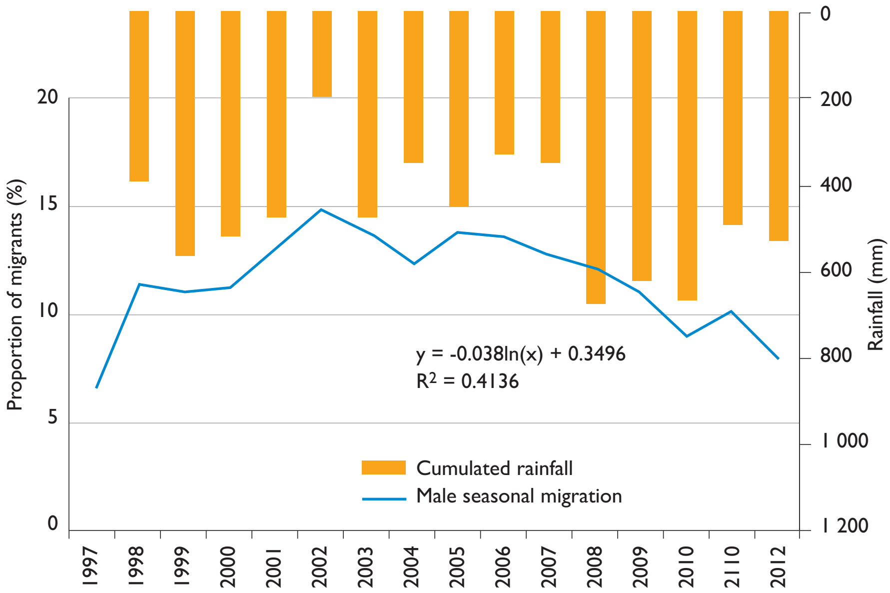

Figure 8.
Proportion of temporary labour migrants in person-years and annual cumulated rainfall. Niakhar HDSS site, 1998-2012.
The percentages of migrants have been shifted one year to the left (n-1).
Thus the associated male migration in 2002 in the graph did in fact occur in 2003.

Even though it is more difficult today to show the link between seasonal migration and rainfall—if only because these movements are tending to become a homogeneous practice among the population—we observe that temporary migration has kept fairly strong sensitivity to climatic variations. For purpose of this analysis, we first chose male migration, found to be more sensitive to precipitation variability. We then set the proportion of migrants in year *n* against precipitation in year *n-1*. Taking the seasonal migration density again (calculated from durations of absence), we observe that male absences are at their maximum (average 13.0%) when cumulated annual rainfall is low (average 529 mm) during the period 1999-2007 (Fig. 8). In contrast, the proportion of migrants decreases when precipitation increases: from 2008 to 2013, cumulated average precipitation was 790 mm and the percentage of migrants fluctuated around 10% (average 10.4%). The link is even clearer for 2002, marked by severe drought (less than 200 mm rainfall during the year) and very poor yields. We note that male migration reached its maximum in 2003 with nearly 15% of the men absent. Finally, the statistical link between the two variables is comparatively strong since after a logarithmic adjustment (see the equation in Fig. 8) the intensity of the relation is $R^2 = 0.41$. An identical estimation for female migration shows a slightly weaker link between precipitation and the proportion of migrants, with a correlation coefficient of $R^2 = 0.36$. All these observations therefore suggest that seasonal migration is still fairly strongly driven by the climate (and its impacts on yields) and that the population is very reactive when faced with difficult situations.

Temporary labour migration responds to various motivations depending on whether it concerns young people or adults, men or women, poor households or richer ones. In the face of environmental and climatic changes, migrations are seen as strategies—often survival strategies—to relieve pressure on the resources of the environment and to enhance transfers of goods and capital that will enable families to remain in their home territory.

Whether considered in terms of number or duration of absence, temporary migrants do not generally account for more than 10% of the total population of the Niakhar HDSS site. In the worst drought year so far in the 21st century (2002-03), the proportion rose to a maximum of 15% of men and 11% of women. In other words, even in the most difficult moments, seasonal labour migration has never been massive and in no way caused the depopulation of the home territory. Calculation of population density from durations of presence (and not just the number of people) shows that from 1998 to 2013 temporary migration reduced population density by an average of 18 persons per sq. km, with population density falling from 184 to 166 after deduction of the durations of absence of seasonal migrants. As previously indicated, the Niakhar HDSS site loses only 100 persons per year because of permanent migration. Consequently, the prime function of temporary migration is not really to reduce anthropic pressure on resources that have become scarcer.

The second explanation generally put forward is that a large proportion of temporary labour migrants provide flows of foodstuffs and cash—from urban to rural areas—to ensure the survival of the families stayed behind in the village (Adjamagbo *et al.*, 2006). We used the repeated '*Cultures et élevage*' survey run from 1999 to 2003 to evaluate the impact of temporary labour migration on the food security of non-migrant populations. This data collection made it possible to assess millet yields harvested by surveyed households for four years (1999-2002), together with the quantities of cereals acquired by the households thanks to migration (Fig. 9). The amount of cereals harvested and consumed were then analysed with reference to the FAO standard (210 kg millet per person per year). Senegal recently set the millet consumption standard at 185 kg per person per year.

During the four years of the survey, millet production as reported by farmers in the Sine never reached the grain self-sufficiency threshold set at 210 kg of millet per person (Fig. 9, orange line). Nevertheless, the shortage is probably not always climate-related. The link between precipitation and grain production is not totally linear during the short period covered (1999-2002). In the first three years, a 15% decrease in rainfall that always cumulated at more than 400 mm did not affect the millet shortfall per person (Fig. 9, differences between the red and orange curves). It must be noted that the poor yields and low grain production with regard to the needs of farming families are also caused by other factors such as the shortage of fertile land and rapid population growth. However, when there is a serious rainfall shortage, as in 2002 when precipitation was 60% less than in the preceding year, millet yields fell significantly, with hardly more than 80 kg per person. Whether the food deficit is structural or caused by the situation, it is covered each year by remittances (purchases of rice, millet, etc.) and donations from migrants (the green line is always above the orange line). Finally, temporary labour migrants have used various support mechanisms to enable the people who stayed behind across the study area to buffer climatic and agricultural shocks and remain on their land.

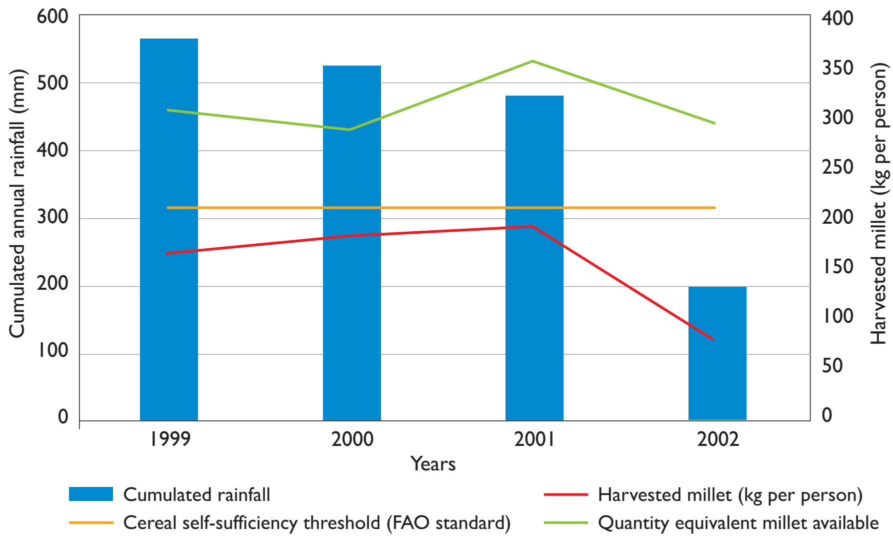

Figure 9.
Rainfall, harvested millet and total consumed cereals, after migrant transfers per person per year. Niakhar HDSS site, 1999-2002.

The two series of maps shown in Figure 10 confirm the results of the preceding graph. Millet yields are sensitive to very strong variations in precipitation and can hardly feed all farming families. Depending on the year, 21 to 28 villages of the 30 surveyed failed to meet the grain requirements of all their population during the four-year period (top maps, villages in red). Nevertheless, purchases and donations of grain thanks to temporary labour migration compensated grain yield shortfalls. In 2001, all the villages in the HDSS site succeeded in covering the needs of their population using migrant contributions in addition to local grain production. However, when the shortage of rainfall is catastrophic, as in 2002, the shortfall in grain production is too marked to be covered by migrant contributions. In 2002-03, a third of the villages could not cover the requirements of their population in spite of the positive efforts made by migrants. Given the weak agricultural and ecological capacities of family farming in the Sine, it would seem that the regulation function of seasonal migration reaches its limits when shortage of rainfall seriously affects grain yields.

The intensity of temporary labour migration is governed partly by rainfall—as shown above—but is also affected by the production capacity of farms. To show the latter link, we re-evaluated the migration rate for each of the four types of farm holding identified using Kohonen's self-organising maps (see above). As before, we examined only the male migration best correlated with the strategies and performances of farms. As this structural and functional typology was drawn up using data collected in 2013, we limited our analysis of temporary migration to the last five years (2009-2013) so that the farms that favoured male migration correspond as best as possible to the situation observed in 2013. The further analysis goes into the past (pre-2009), the more our typology diverges from the farm holding conditions that were at the origin of migration.

Generally, and in spite of these reserves as regards interpretation, we observed that temporary labour migration is a behaviour common to all types of farms. Whatever the reasons (survival or earning money), male seasonal migration is a phenomenon related to precipitation for all the farm categories (Fig. 11). Farms undergoing decapitalisation (i.e. when all of the production has been consumed) or with a shortage of production capacity, and farms with innovation and investment capacity call less on male temporary migration when annual rainfall increases, as happened during the period 2008-2013 (Fig. 11).

Although the same migration trend is observed in each of these farm categories, the degrees are markedly different. When extreme situations are observed, that is to say farms with a lack of production capacity and farms capable of investing, we observed that at all times the former have had an average of 25% more migrants than the latter during the last five years.

Farms with under-production are defined as those with substantial land capital (5 ha), but where only half is used. They have fairly small investment capacity and a very low level of equipment. Their labour force is under-used (3.1 workers per hectare farmed) and an average of 41% of household members have non-farming work. Nearly all the farms in this category purchase grain (94%) to feed the household.

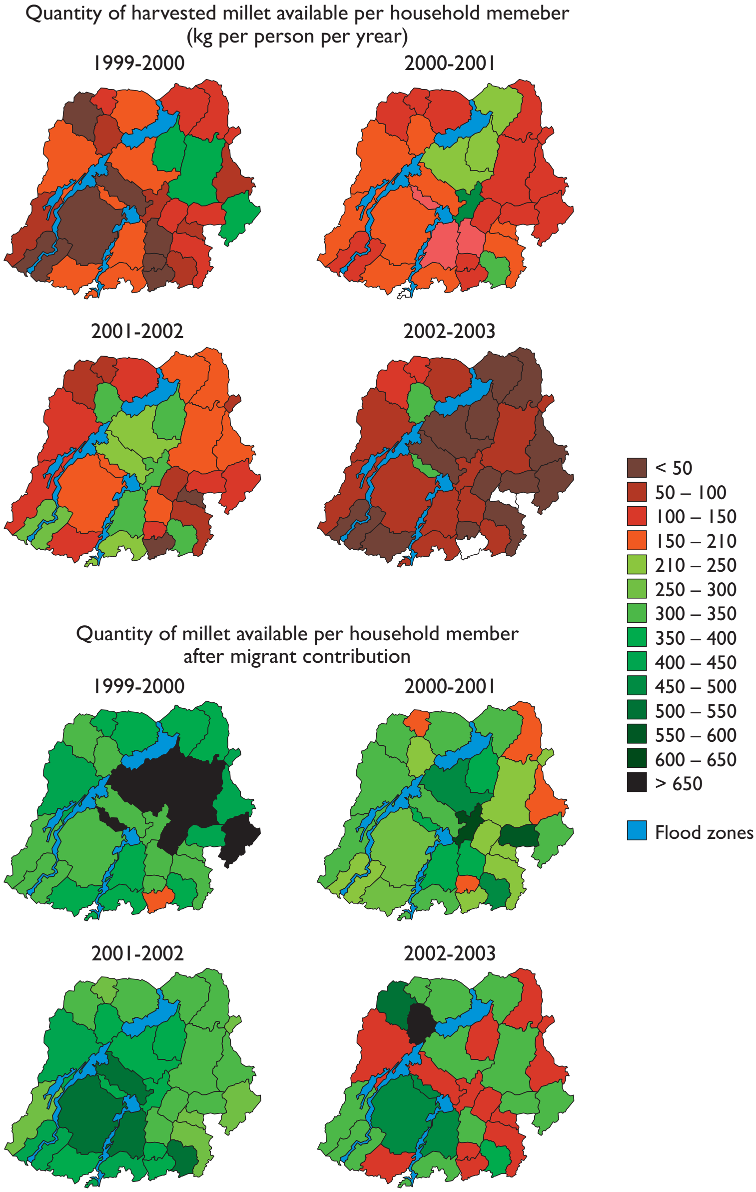

Figure 10.
Distribution by village of the quantities of harvested millet and the total quantities of grain consumed per person per year after migrant contribution. Niakhar HDSS site, 1999-2003.
The areas in shades of red are those where the quantity of millet does not attain the 210 kg per person per year that is necessary. In contrast, the areas in shades of green have quantities that exceed this standard. The darker the shade, the further the distance (negative or positive) from the threshold of 210 kg per person.

For these holdings, labour migration is thus a strategy for adaptation to agricultural production with a structural shortage and not sufficient to cover the household's food requirements.

In contrast, the farms that make the least use of labour migration are generally large (average owned land of 4.5 hectares, and one household in two also farms borrowed land), have a large labour force (10.2 workers) and much equipment. A large proportion of their farm production is intended for sale, with 40% of the usable agricultural area devoted to groundnut and watermelon, and one household in two fattening cattle. These farms also ensure food security for the members of the household. Only 20% of the farms purchase grain because the harvest has been too small. Finally, given their farming and trade performances, these farms make little use of male labour migration to cover the essential needs of the household. However, migration is not totally absent from the range of strategies used by these farms. From 2009 to 2013, an average of 9.5% of the men were absent from their farms, probably because they wished to increase the investment capacity and capitalisation of their farms.

After 50 years of intense circular mobility between the large cities in western Senegal and the villages in the Niakhar zone, temporary labour migration today concerns practically all persons of working age and responds to both constraints—those linked with increasing anthropic pressure on soil and water resources, food insecurity and the small capacity for change in family farming—and choices: meeting the cash requirements of young people, those attending schools or of marrying age and adults

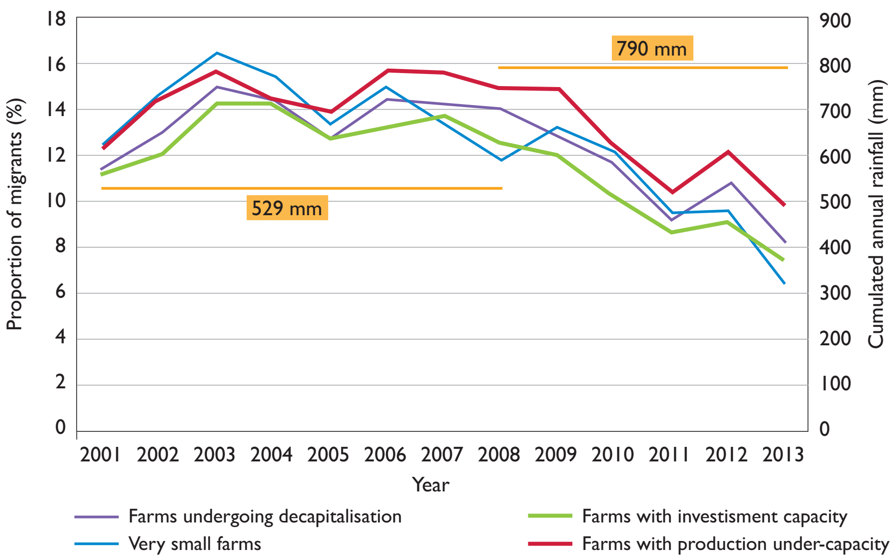

Figure 11.
The proportion of male temporary labour migration (in person-years) according to the type of farm.
Niakhar HDSS site, 1998-2013.

who wish to invest in an economic project. However, in spite of the increasing complexity of the causal factors, climatic uncertainty still marks seasonal migration strongly.

Conclusion

Even before climate change became a public debate issue, internal migratory movements from the south-west of the groundnut belt had long been linked with high population density in the home environment and the environmental shocks in the Sahel in the 20th century. Today, migration is becoming widespread and more intense while population is growing at a rate never seen before and climate is changing, with more uncertainty and extreme situations.

However, movements of population cannot be seen as an exodus or abandonment—either today or in the past. Permanent migration is still very rare in the Niakhar zone, and labour migration, extensive throughout the area, always entails long-distance relationships with home villages and the return of migrants after a more or less short-term absence.

These circular movements are not an escape either. In certain very dry years, a fraction of the population may run from the resulting food crises. This was the case in particular in 2003 after the catastrophic harvest of the 2002 rainy season. However, farmers have never run away from their fields at any moment, either temporarily or permanently, even during the ecological crisis of the 1970s. The climatic and environmental changes of the past 50 years have indeed hit agricultural yields and food security—sometimes dramatically—but the land has not become unsuitable for farming or even lastingly inadequate for feeding a large number of people. So the farmers in the Niakhar zone can make a strategic decision to leave their home base but never brutally or permanently, or simply choose to miss an agricultural season.

Finally, temporary labour migration is not a mark of failed adaptation. Of course, these trends could be less intense if family farming in the Sine had capacity for change and could improve its performance. But we have also seen that even the most innovative holdings that best ensure the food security of the family do not rule out migration. This strategy has become part of habits and is useful for young people who must fund their education and also for adults who wish to invest in their farms. Furthermore, migration would truly indicate failure if it were accompanied by agricultural abandonment and responded to a total inability to feed the population. The strategy is quite the opposite; thanks to remittances and food donations from a few, the majority of people can stay in the village, continue to farm the land and cover part of the essential needs. Migration is clearly adaptation rather than failure to adapt.

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Chapter 15

Female migration, a non-farming strategy for adaptation to climatic and environmental changes in the Imanan (Niger)

Amadou Oumarou

Introduction

Labour migration of rural girls who go to towns as domestic servants is a very widespread phenomenon in sub-Saharan Africa. In Niger, although it has developed remarkably in recent years, it is still little known. However it does have substantial proportions in various places in the country. Such migration is mainly seasonal and takes place during slack work periods of the year, that is to say from October to May. It is commonly referred to as an 'exodus' and, in addition to its economic purpose, plays a significant social and cultural role for rural populations.

However, a new form of migration has been developing in the Imanan district for nearly two decades. This is the migration of women to Niamey, the capital of Niger, where they work as 'maids' in urban households during the dry season. This practice concerns all the sociocultural groups in the district in variable proportions and concerns both girls and married women.

This chapter is based on research results[1] and has three objectives: a) analysing the causes of the scale of female migration in the district of Imanan, b) examining the links that can be established between this practice and the various effects of climatic and environmental changes in this area, and c) examining the forms of social change in the district resulting from the migration of young women.

1. The results of a multidisciplinary research project are presented here. Entitled '*Les changements environnementaux et sociaux en Afrique: passé, présent et futur* (ESCAPE)' (Environmental and social changes in Africa: past, present and future), it has been running in four West African countries (Benin, Mali, Niger and Senegal) since 2011. In Niger, a team of three LASDEL scientists are performing research on the human sciences aspect. This chapter results from the 'Perception and signs of climatic and environmental changes and non-farm responses made' investigated in the Nigerien administrative zones of Imanan and Dantiandou.

Recent studies showed the importance of the geographical mobility of women for their capacity to get jobs that improve their incomes (JACQUEMIN, 2009; DESTREMAU and LAUTIER, 2002; COMOE, 2005). This form of spatial mobility is analysed as both a strategic requirement for women and a practical means of obtaining goods (financial, material and human). For this chapter, the theory of the new economics of labour migration (Stark *in* FLAHAUX, 2011) seems appropriate for understanding this form of female migration. Indeed, this theory has two main features: a) it places the decision to migrate at the centre of the family unit b) it analyses the migrant as a person who wishes to attain a precise objective and who will return to his/her home area as soon as his/her economic situation is sufficient to face the risks to which the home household is exposed.

This study was constructed with a socio-anthropological approach involving the use of a set of techniques for the collection of quantitative data. They consisted of semi-directed interviews, observations and case studies. The 'strategic groups'[2] surveyed were the migrants themselves, their employers and/or guardians in Niamey, their family (blood relations or relations by marriage) and the local religious, customary and administrative authorities. A total of 48 interviews were conducted in both the migrants' home region (the Imanan) and the host area (Niamey).

– Four villages were investigated in the Imanan district: Bonkoukou (the main village of the district), Balley and Kochilan Bella, which display much female migration, and Kochilan Surgu, a village where this is small.

– In the city of Niamey (the destination of these female migrants), four places were identified as sites for the concentration of immigrants from the Imanan. These are two places where migrants are housed by a person from the district: the National Museum and the headquarters of the union *Union des syndicats des travailleurs du Niger* (USTN) and two other sites where the migrants are housed in a shed, in a house or in the open air. These are Bukka Bokoye and Sabka Lahiya hotel.

Here, a description of the framework of the evolution of female migration in the district of Imanan is followed by analysis of its main determinants and, finally, examination of the issues involved.

The district of Imanan, a framework for the analysis of female migration in Niger

This first point describes the geographic context of the rural district of Imanan and forms of climatic and environmental changes. It is followed by analysis of the evolution of female migration.

2. OLIVIER DE SARDAN (2003: 179) talks in terms of 'strategic groups' to describe 'more empirical social groups of varying size that defend common interests, in particular through social and political action'.

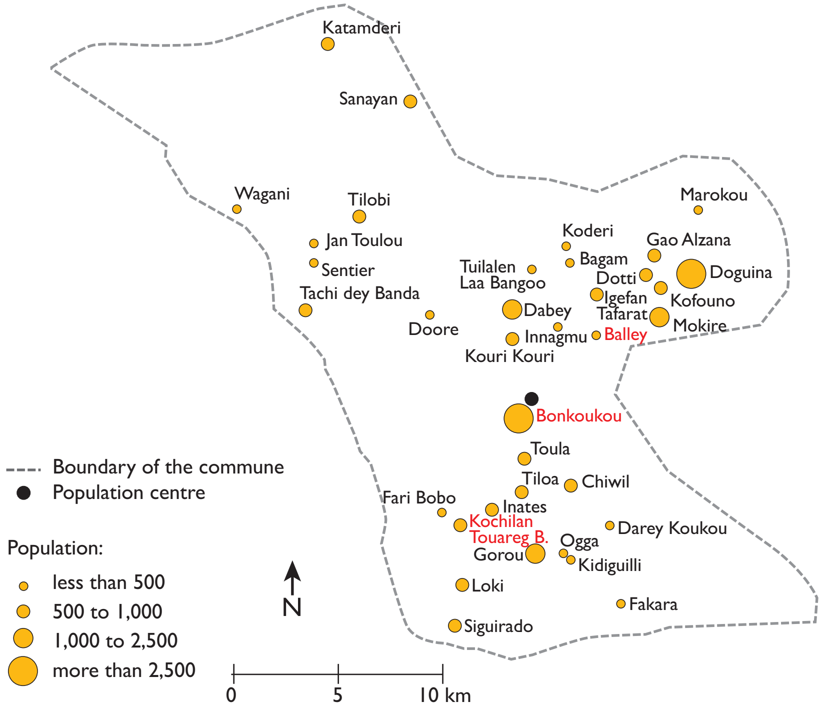

Figure 1.
Map of Imanan commune.
Escape sites in red.

Female migration, a relevant subject for study in the district of Imanan

There are several forms of migration according to the reason for the decision to leave (economic and/or social) and the stakeholders concerned (men, women, young people, old people).

In several Nigerien districts, 'internal migration triggered by rural poverty' is the most visible. It long remained a masculine phenomenon. However, research by Locoh (1995) and by Comoe (2005) showed that the traditional migratory flows in West Africa that mainly involved men were gradually becoming more feminine. This feature is explained by two major factors: the socio-economic changes that are affecting the home societies of female migrants and the policy favouring family grouping in the destination zones. In fact, 'the social roles assigned to each sex are undoubtedly constraints for the migration of women' (Tahdani and Torado *in* Locoh, 1995: 92).

However, in Nigerien rural areas (especially in the district of Imanan), this social organisation that institutes 'social roles', devoting a man/woman distribution of tasks between members of the community, seems to be developing. Female mobility now appears to form new dynamics that changes local approaches to economic, social and cultural structures. A geographic and socioeconomic description of the district of Imanan gives better understanding of the issues of female mobility in this area.

Imanan rural district is about 140 km east of Niamey. It has an area of 506 sq. km and is bounded to the east by Kourfeye-Centre rural district, to the west and south by that of Tondikandia and, finally, to the north by Filinguée urban district.

Overall, the morphology of Imanan consists of relatively fertile low laterite plateaux in the south and north-west of the district, crossed by the less fertile Dallol Bosso valley.

As regards demography, the district has a population of 37,772 persons according to the general population and housing census (RGP/H, 2012). The population is made up of 70% Tuaregs (Surgu, Bella and Garassa), Zarma, Peuls and Haussa, who are in a minority and distributed throughout the district.

As regards the economic aspect, the population of the district of Imanan is devoted mainly to crop farming and livestock. The entire population grows rainfed crops. However, livestock farming is performed mainly by two sociocultural groups—Peuls and Tuaregs. Fattening is the form of animal husbandry practiced in the other communities.

These occupations are still affected by climatic events and demographic pressure. Indeed, for more than two decades, climatic variations in the form of poor spatio-temporal distribution of precipitations and continuous soil degradation mean that farming systems no longer meet the requirements of households.

Deforestation and the drastic shrinking of herding routes and grazing areas, the gradual disappearance of plant cover and strong sales of crop residues and straw also form a major obstacle to livestock farming.

As the yields of the main occupations are precarious, the population seems to be increasingly turned towards crafts, small retail operations, market gardening and migration. Although these are still secondary activities, they are essential for survival. Although female migration is an old practice, the context means that it is growing today. The forms and recent amplitude of the practice are examined below at the scale of the district.

Female migration, a growing practice in the Imanan

Female mobility in the district of Imanan has changed both in the number of migrants and their status and the deep-seated reasons for their departure for Niamey.

The surveys performed within the scope of this research showed that 20 years ago female migration was for conjunctural reasons. Women left for Niamey only very rarely and in clearly exceptional circumstances. Studying female migration in Côte d'Ivoire, Comoe (2005: 113) noted that 'for a woman, migration is first a question of role, migrating is an individual decision, behaviour that runs against the expectations of society and is therefore considered to be an unconventional act'.

Female migration was observed only when crop yields were short. In this case, only women who were heads of households and who had relations in the city could travel to seek a complement for their food stocks[3].

Migration to Niamey enabled these women to obtain foodstuffs: millet, maize, rice, cassava flour *(gari)* and leftovers of prepared foods[4] going by the local name of *kussu maassa*. In addition to food, they were sometimes given a little money for purchasing grain.

This type of movement is a form of short duration survival migration aimed at responding to occasional difficulty with regard to food. A search for aid for food, money or clothes after bad harvest years was thus the main reason for these women to go to Niamey.

In a small proportion, this form of migration then concerned young married women and girls who visited relations who lived in Niamey. This act of courtesy concealed a search for new clothes and 'rest'. Indeed, for a female 'villager', being in Niamey means a life without physical efforts and hence without work. The work concerned here is fetching water from the well (often deep and/or remote), gathering firewood, pounding millet and preparing meals. Not doing these everyday tasks means a real rest for these women. Going to Niamey was thus an opportunity 'to care for the body' as these migrants said in different interviews.

> 'The oldest women only left for Niamey during food crisis periods in order to find food, and the younger ones to get clothes and profit from life in the city: resting for a while, gaining weight and becoming very clean. But before going to Niamey, they had to be sure that the relation they were going to stay with was self-sufficient and could handle their requests' (a female migrant from the village of Bonkoukou, November 2013).

A stay in Niamey was thus a time when women profited from 'the living conditions of the city' to become clean and to seek a new physical appearance that expresses a certain 'affluence', a certain 'comfort' (recorded in various interviews). When they returned to the village, they stood out from the other women by their dress (type of clothes and degree of cleanliness).

Search for clothing in the city is closely linked with the precariousness of the food situation of village households. Purchasing clothes is closely dependent on the sale of part of the crops. This is only possible when annual crops are satisfactory.

This type of journey concerned only a few families as years of poor harvest and severe food shortages were not very frequent.

> 'Before, even if there were years of drought and shortage of food, the pattern was less regular. Five or six years or even more could go by with a food shortage. Rain was more plentiful and better balanced. There was rain from sowing to harvest and all the villages in the zone had the same season. But now, one village might be hoeing and another harvesting even if they are close to each other' (discussion with a farmer in the village of Bonkoukou, November 2013).

3. Several authors (Bisillat, 1996; Koné and N'Gessan, 2005; Hambally, 2012) defined a female head of household using several indicators: widow, prolonged absence of the husband resulting in his wife living alone, economic precariousness of the husband meaning that his wife must cover the essential needs of the household. In general, this category of woman has several dependents and elaborates a range of strategies to feed them (paid labour, small-scale trade, use of local social networks, seasonal migration, etc./).

4. Crust formed at the bottom of the pan when a meal has been cooked.

The observations above show that two major features can be used to analyse this form of female migration. They are first of all bad harvests, which are the result of meteorological events, and then the fact of having a relation in town.

> ‘ […] you couldn’t go to Niamey if you didn’t know anybody! A woman who did that would not be seen with a good eye as none left to look for work then’ (a woman from the village of Bonkoukou, November 2013).

Girls who go to the city stay with a relation and for a predetermined length of time. They help the host family with domestic tasks without their contribution being seen as paid work. This form of migration is comparable to that of ‘the young niece’ described by JACQUEMIN (2009), who showed that in Abidjan the young niece is never paid in cash, but is housed, fed, clothes and helped in case of illness by her employer/guardian, who must also ‘do something’ (trousseau, pagnes, crockery, sewing machine, a small sum of money, etc.).

This form of mobility can be defined as a rare practice used during occasional food shortages, following less complex motivation that is clearly defined and associated with a search for food or clothing.

But today, even if this type of displacement still exists in the Imanan administrative area, it is giving way to another form of female mobility that is much more affirmed and systematic.

The new form of female mobility: many reasons

The mobility of women in the Imanan administrative area who travel to Niamey has now become a form of mobility whose main motivation is the search for a paid job. But this overall motivation conceals more individual approaches related mainly to the matrimonial status of the migrant or her age, her sociocultural group or the nature of her social network.

Dwindling agricultural production

Crops and livestock farming are essential activities for the local economy and seriously affected by the climatic and environmental changes observed in the zone. The changes result in a drastic decrease in farm yields and livestock numbers. Several surveys have shown the poverty of the farmland (‘*Laboo bu!*’ ‘The land is dead!’) when the crops are compared with those of past decades.

> ‘In the same field that I use today, the usual crop is 150 to 200 bundles of millet. But now I harvest only just half of that and I have more mouths to feed […]’ (a farmer from the village of Balley, August 2012).

Indeed, whereas income from crop and livestock farming in the 1970s was sufficient to cover food requirements and other types of essential needs of the household, it can be seen clearly in the surveys that farmers in the Imanan administrative area can no longer grow sufficient grain in their fields to meet the food requirements of their households.

> 'Before 1984 (a year of extreme drought), I always had some millet in my granary before the year's harvests. But since then I have to buy millet even before the seventh month of the farming year. The fields don't yield well any more. In recent years, although the rains are not late, there is a succession of heavy rains and the seedlings don't grow; otherwise, crop pests arrive [...]' (a resident of Belley Koira, August 2012).

Farmers have developed several strategies to make up for the deficit: sale of livestock, goods or equipment, paid labour, sale of farming residues, straw or charcoal, seasonal migration, etc. There is substantial literature on the strategies used by farmers to handle food crises (ALPHA GADO, 2010; DRAME YAYE and ALPHA GADO, 2006; BALLA *et al.*, 2009; MOUNKAILA, 2004; OUMAROU, 2013).

Given the poor performances of farming combined with strong demographic growth (3.9%)[5], the resources drawn from male migration no longer cover the requirements of households. But this role gradually dwindled because of the continued failure of heads of households to cover core family obligations—food and other basic needs of women and children (clothing, health care, body care products for women and the assembly of a trousseau for girls).

The causes mentioned for this erosion of the responsibility of heads of households are associated mainly with poverty. Several features are listed by people surveyed to describe the climatic and environmental changes. They include:

– variation in rainfall: the population of Imanan administrative district mention substantial changes in annual rainfall for a number of years. The changes concern the quantity of rain recorded (the local method for measuring rainfall is the depth of temporary ponds and the time they take to dry out after the date of the last rainfall), its distribution in time (the number of months covered by the rainy season) and space (the area covered by a rainfall event) and also the lateness or earliness of the first rains;

– disturbance in the nature and strength of winds: this concerns the appearance of reddish dust the day before the first rains (a phenomenon not previously known to the people in the zone) and changes in the direction of winds during a single season;

> '[…] during the ''*jaw*'' cold season, the Harmattan generally blows from west to east. But in recent years the cold seasons are complicated, with winds from all directions and we can't understand them!' (a person interviewed in the village of Bonkoukou, October 2012).

– marked change in temperatures: the temperatures in the various seasons are not those known before (higher in the hot season and lower in the cold season);

5. Report by the Institut national de la statistique (2012).

> 'We have less and less mastery of the limits of the seasons. Usually, we understand when the end of the cold season starts because of the temperature that rises throughout the day. It may now be cold on one day, very hot on the next and then the cold comes back on the next day. We're lost in this mixture!' (a customary chief in Imanan administrative district, October 2012).

– disturbance of local knowledge of the advanced signs of changes of seasons[6].

The climatic changes mentioned above are accompanied by changes in the environment that the population has difficulty in explaining, even if people establish basic implicit links. Environmental changes are expressed as follows:

– the disappearance of several shrub species, an in particular *Ziziphus mauritania (darey), Balanites aegyptiaca (garbey), Acacia polyacantha* spp. *(dan), Grewia bicolor (kélli), Acacia macrostachya (tchidi), Adansonia digitata* L. Bombacaceae *(koo nya), Combretum nigricans (déli-nya)* and herbaceous plants that are used as food or for medicinal purposes: *délounfa, hanza, Gynandropsis gynandra (fubey), Leptadenia Hastata (hanamm),* etc.;

– the appearance of new shrub and herbaceous species of little use: *Piliostigma reticulatum* (*kosorey*);

– the disappearance of animal species from the area. The recent disappearance of fauna in the administrative area was mentioned in several interviews:

> ' […] when we were young, we used to go hunting from the food of this hill and on the plateau. Hunting was organised every year and people caught hares, does, partridges, etc. But now there's nothing. You hardly see a mouse when you cross the area!' (man about 40 years old from the village of Bonkoukou, November 2012).

– continued soil degradation caused by various factors, the most frequently mentioned being erosion, leaching and sanding up.

The literature on the relation between migration and environmental factors centres reflection on sudden natural catastrophes such as floods, hurricanes, landslides, droughts, etc. These events naturally cause massive population departures. For example, drought in Niger caused the displacement of a million people in 1985 (Hammer *in* Piguet, 2008).

Here, climatic and environmental changes form part of a slow process that has clear effects on the economies of households and this contributes a movement of women to the city. Indeed, all the climatic and environmental changes mentioned have effects on the quality of the land farmed and hence on the farming productivity of households, whose main activities are still rainfed farming and animal husbandry. Related activities that are no less important are also disturbed by the limiting of access to natural resources (particularly for household equipment; for the home, trousseau).

The effects of the climatic and environmental changes are seen as a succession of causes that affect the entire lives of households. This is shown diagrammatically in the figure below.

6. This point is examined in detail in Chapter 5 ' When nature talks to us — Comparative analysis of representations of climatic and environmental changes'.

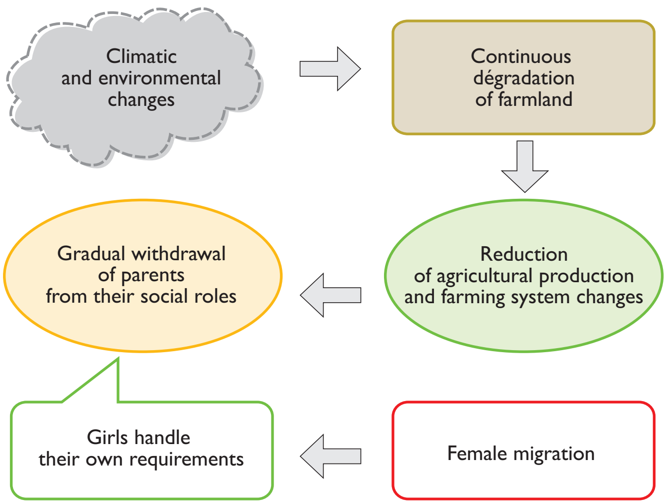

Figure 2.
The causal cycle of female migration in Imanan administrative ditrict.

A close link is established in several interviews between the economic difficulties of households resulting among other things from these climatic and environmental changes and labour mobility of women in the city of Niamey. However, several other factors are involved to varying degrees in the amplification of this phenomenon that concerns both an increasing number of people and the diversity of the persons who migrate.

> 'It is difficult to give the precise number of women who leave for Niamey at the scale of the administrative district, but we know that we can say that four households in five are concerned. If the woman of the household does not go, at least one of her daughters leaves […]' (a local councillor in the district of Imanan, November 2013).

It is important to see whether the economic situation of households can be the only factor accounting for the magnitude of this practice. Field observations have shown the existence of several families belonging to precise social groups and that are not involved in female migration. This makes it possible to examine other aspects that might affect the scale of the practice in Imanan administrative district. Among other things, they include the sociocultural group involved, matrimonial status and the age and social network of the migrant. These features can be relevant indicators for analyses.

Sociocultural category as a factor in the likelihood of female mobility

Female migration is not on the same scale in all the social groups in the Imanan administrative zone. Is there a link between female migration and membership of a sociocultural group? It is reminded that Tuaregs form the dominant group, consisting of Bella, Surgu and Garassa. The Bella form the group in which the largest number of migrants are recruited. In contrast, Surgu and Garassa women are rarely concerned by mobility because of their social position and economic level.

For the people interviewed, the Surgu form the 'nobility', the class that holds local customary power. Their social position obliges them to respect social standards that include, among other things, 'abstaining from carrying out paid work for a person other than a Surgu'. This aspect is highlighted by persons interviewed to account for the absence of migrant Surgu women. For them, a Surgu women employed as a servant in the city is 'an aberration' (*kan si hagu*), 'shameful' (*haawi*) for the woman concerned, her family and the community as a whole. But beyond these purely cultural considerations, there are economic reasons that contribute to explaining why Surgu women do not migrate. In fact, the Surgu have more fertile bottomland and capital in the form of livestock that enables them to face the annual bridging time. This means that they are less vulnerable than the other communities in the zone. However, it is noted that Surgu women go to Niamey for courtesy visits to their relatives.

The Garassa form another Tuareg subgroup. They are specialised in various craft activities. The women of the community work with leather, perform tanning and make pillows and decorative objects. The sale of these items brings them fairly large incomes. They are also specialists in the traditional hairstyle (braids). All the women of the other communities in the area have their hair done by Garassa women. The latter are paid in kind or cash. Payment is generally in the form of an annual contract and consists of a bundle[7] of millet or sorghum at harvest time. Other presents are added to this tacit contract. For example, the women whose hair is being braided bring one or two measures of grain[8]. Likewise, each time that one of their clients has a baby, the Garassa are given money and a piece of meat from the animal slaughtered on the day of the baptism. When there is a marriage, they receive up to 15,000 CFA francs in cash.

All these activities bring in comparatively high incomes for the Garassa women. This partially accounts for their absence from female migration. The rare journeys of Garassa women to Niamey are within the framework of family meetings. Indeed, several Garassa men perform their traditional craft and work in Niamey. They make leather shoes, bags and belts and decorative pictures. When their wives join them, the latter work as hairdressers. This form of female migration is described by Comoe (2005) as 'rewarding' insofar as the woman migrates with her husband, joins him or follows another member of her family; independent migration by women is very quickly associated with prostitution (Pittin *in* Comoe, 2005: 92).

It can be seen from the above that Surgu and Garassa women are less concerned by migration. For the former, even if the reason put forward is that they belong to a noble social group, the real reason is above all that they have sufficient resources to cover family requirements. The case of the Garassa better expresses the link between

7. A bundle of millet is the measure used by farmers to evaluate their crop. A bundle can be the equivalent of 25 kg of millet in Imanan.

8. The measure here is a local recipient that contains two litres.

economic conditions and female migration. Profitable traditional activities that give a certain economic weight at district level mean that the women do not have to migrate to the city.

Membership of a social group influences a woman's possibility of migrating as it determines the possibilities of access to the resources of the members of a household at the local level. For example, being a member of a Garassa family gives more opportunities for a woman to have activities that generate income. A stated by LOCOH (1995: 8), it is also because 'far from limiting themselves to biological reproduction and generation solidarity, family groups have a determinant influence as production units and make a considerable contribution to social control by the transmission of the standards and values that govern behaviour'.

Matrimonial status and age as potential factors in migration

Although female mobility used to be a practice of female heads of households, the phenomenon is now spreading to other categories of women in the Imanan administrative district, and especially married women and girls.

Aged 20 to 35, these young women are strongly present in this migration activity even if they are the smallest category in numbers and stay in Niamey for shorter periods than the others. The reason put forward is mainly the refusal of certain men to allow their wives to go and work in the city. A return date is set in advance for those who succeed in gaining the assent of their husbands. A fairly common saying is still relevant here: 'The first duty of a husband is to provide for the various needs of his wife'. The men who allow their wives to go to Niamey take a knock and so do not want them to say for too long.

> 'We don't always want our wives to go to the city. But often, when we cannot afford to buy them what the migrants bring back from Niamey, we are obliged to let them go and try their luck' (the husband of a migrant from the village of Kochilan Bella, December 2013).

The largest category of migrants consists of girls 10 to 19 years old. There are no statistics recording the precise numbers but cross-referencing interview data shows that eight out of ten families in the district have girls who migrate. They are mainly girls who have just married but have not yet moved into the family home and girls in the process of getting married. The youngest of them (the under-15s) form a numerically small subgroup and go to Niamey on a 'fosterage'[9] basis.

The main reason mentioned to justify the large scale of migration by young girls is the assembly of a trousseau forming the equipment for the bride's house.

The trousseau has changed, both as regards the type of goods and its role in the different households. The table below shows the change in the composition of the trousseau.

9. A term coined by GOODY (1969) and borrowed by JACQUEMIN (2002: 308) to describe form of circulation of children in family solidarity networks—different to adoption—that allows the host family to keep a girl to help with domestic tasks.

Tableau 1.
The change in the wedding trousseau in the Imanan administrative district.

	Old form	**New form**
Composition	– one wooden bed *(tessat)* – one bed made of millet stems *(dangarsa)* – one mat in doum palm leaves *(tangara)* – one leather pillow *(furu kanga)* – cups *(cansi)* – calebashes *(gaasu)* – hanging objets (*deegara)*	– *two* beds *dungunkuturu, mairunfa, karbanda, kano-ize*, or *formica* – two mattresses – a table – plastic floor covering – wall covering – a dozen carpets – two chairs – cups
Method of obtention	Made or purchased	Purchades
Persons in charge	The bride's parents	The bride

Source: field data de terrain, September-December 2013

The table shows that the wedding trousseau used to consist mainly of items based on local products that were therefore easy to obtain. But making these things has become more difficult as the degradation of the environment causing the disappearance of several shrub and herbaceous species has contributed significantly to changes in the items forming today's wedding trousseau for girls in the Imanan. Obtaining these goods requires resources that are not always available locally. Parents used to pay for the trousseau but small agricultural productivity means that they can no long cover this cost and this encourages girls to work on assembling it.

> 'Before, only a little money was enough for a young man to get married. I got married two years after Kountché took power (1976) with only 12,500 CFA francs. This was amply sufficient to fit out the house of a bride. The equipment consisted of very few things in comparison with what is done today. You just had to buy a bed with wooden slats *(tessat)*, a bed made of millet stems *(dangarsa)*, a palm leaf mat, a leather pillow and a few cups and calabashes. It was all so simple and easy. In fact, some women made the mats and millet stem beds for their daughters and so they didn't have to buy any. Really, there was none of the large expenditure that complicates young people's weddings today' (an inhabitant of Bonkoukou, November 2012).

Today, trousseaux consist of a new generation of furniture, utilitarian objects and decoration. *Tessat* and *dangarsa* beds are replaced by other types, the most frequently mentioned being karbanda, *doungounkoutourou*, *kano izé* and formica beds. These beds appeared in the villages together with tables, carpets, wall coverings, chairs, etc.

In addition to being costly, trousseaux have become like an arena for competition between young brides. Each tries to stand out by the quantity and quality of the items forming the trousseau. Here, this takes the form of the expression of the economic and social identity of the bride. Its size and the quality of the items form a factor in the integration or marginalisation of the bride in her peer network.

> 'When a girl marries, people pay great attention to what she brings in the way of clothes, beds, decorative items, etc. People come from the whole village and even from nearby villages to attend the wedding and to make comments about the trousseau. Thus every girl first of all wants a complete, substantial trousseau on her wedding day' (a woman from the village of Bonkoukou, November 2013).

This competitive spirit in the assembly of a trousseau is the factor most commonly mentioned to explain the scale of journeys by girls to Niamey.

All categories of female migrants do various types of job once they are in the city:

– domestic work: this is the most common activity of migrants from the Imanan, but concerns mainly girls and young married women. They perform various domestic tasks: cooking, washing up, washing and sometimes looking after babies. The latter job is generally reserved for the youngest migrant girls aged from 9 to 12. Household staff are paid 3,000 to 20,000 CFA francs per month. Four key factors determine the amount: the age of the migrant, the nature and scale of the tasks to be performed, the migrant's experience of this work and the level of the employer's income;

– small-scale trade: this consists of selling fritters or *moringa* leaves, known as *copto* in the Zarma language, etc. This work is done mainly by female heads of households;

– the sale of food: this is a special activity insofar as not all migrants are capable. It requires considerable initial funds. The women who do it generally form a team of four or five to cook and sell rice; this is the case of the migrants within the premises of the National Museum. What is important is that they employ and/or house other migrants from the same district in their sales area.

All these jobs mean that migrant women can earn money for the various requirements, the most important shown by the interviews being assembling trousseaux for girls, completing family food stocks, buying new clothes and presents for the family members who stayed in the village and 'looking after their bodies' (caring for their physique by means of good food and rest).

Social networks, an incitement for migration

In the Imanan administrative district, women's decision to migrate is not just associated with a need to meet immediate requirements or a desire to travel. They also have to obtain information about the practical features of life and access to work once they are in Niamey. Access to information depends on the potential migrant's social network. Discussing theory of networks and social capital, PIGUET (2013: 150) showed that 'networks are both sources of information and providers of aid and support for travelling and for settling in the destination country'.

Having a network thus means that the prospective migrant has the possibility of finding work and has practical support for her stay.

> '[…] it's those who return who say what you have to do to get work once you're in Niamey. They help us to look for work via friends of their employers or their guardians.'

This form of placement is the most common and the most effective. It makes it possible to establish mutual confidence between the new employee and her employer more rapidly.

> 'When you find work through a friend, it's really better because if she has got on well with her employer you will get on just as well and you may get presents in addition to your pay.'

The second way of finding a job is the door-to-door method in which the migrant goes from house to house in the city to ask for work as a maid. However, this strategy is used by migrants with a poor social network.

In addition, a migrant must have somewhere to stay while looking for work in town. This is where migrants live in Niamey during their stay. Comparison of the data collected shows that various places in Niamey are possible for migrants from the Imanan:

– with people from the home district: migrants are housed by a family member or simply by someone from their home village. These are mainly the wives of labourers, caretakers or masons. It is the case of the masons within the premises of the National Museum or of the caretaker of the USTN, where several migrants are housed. A kind of tacit ‘win-win’ partnership takes shape between the migrants and their ‘guardians’, but without this being an enounced condition. Each migrant brings back from her workplace a meal that she shares with the members of the host family. The greater the number of migrants, the more dishes there are and this enables the host family to handle its life better;

– alone (in independent housing): according to the statements made, some migrants live independently in a shed or in a hut they build themselves in non-built land, in the industrial zone (Bukka Bokoye), near the green belt or in abandoned public places such as the ex-hotel Sabka Lahia. This type of lodgings above all concerns women heads of households who can house young migrants;

– at the employer’s house: some employers agree to house their domestic staff, although this is not very common. The migrants who live in employers’ homes are considered as fully-fledged maids, even if they have to learn everything. They must be taught household tasks (cooking, shopping, various kinds of cleaning) and also learn about life in town. Staying in their employer’s home implies both a form of integration in the family (living space in the home, more visible relations with family members) and a kind of ‘veiled marginalisation’. Indeed, the spatial overlapping in which the life of the servant and that of her mistress are juxtaposed creates a feeling of encroachment, of lack of privacy and irritation in many situations (DESTREMAU and LAUTIER, 2002: 253).

The surveys show that most migrants do not want to be housed in their mistresses’ homes because they would have less freedom, especially in the evening. This expresses the migrant’s desire for freedom.

An ambivalent phenomenom

For the migrants, their families and the community in general, female migration as practised in the Imanan administrative district has advantages and limits that deserve examination.

A factor in the increased autonomy of women?

Migration of women to Niamey has financial, material and symbolic advantages. Income from migration means that the women concerned gain a degree of autonomy.

More visible participation of women in covering the food requirements of the household

The resources drawn from migration enable women to participate more actively in covering the food and material needs of households. In the particular case of girls, migration enables them to pay for a large proportion of their trousseaux. One of the women interviewed gave this explanation:

> 'Migration has several positive aspects for us. First, we help the men to cover the food requirements of the household. Then, the girls manage to cover all or a large part of the expenditure on their trousseaux and this goes towards compensating the poverty of the parents, who thus feel relieved' (a migrant from the village of Kochilan Bella, November 2013).

Thus migrants participate greatly in the management of households through the purchase of food, remittances or sending leftover food ('*hauru kogo*') when they are in Niamey.

More marked economic independence of girls

Their stay in Niamey means that girls obtain resources that enable them to buy their trousseaux. This new role is changing somewhat the relations between men and women in the administrative district of Imanan. Indeed, by covering the large expenditure related to their marriage, girls take responsibility and thus have greater decision with regard to the choice of a husband.

A new appearance or 'look' for migrants

On their return from the city, all categories of migrant (from young girl to older women) differ from those who stayed in the village by their jewellery, clothes and physique. The fact of spending several months without doing 'physical work' (pounding millet, drawing water or collected wood) means that migrant women have softer, more feminine bodies than those who stayed in the village. These new physical features mean that they are attractive for the villagers. Migration thus contributes to improving the social image of women in the Imanan.

In addition to these positive effects of female migration, many persons interviewed consider that female mobility is more a cause of harmful consequences for the migrant, her family and the community as a whole.

A perversion of social values in the Imanan

A stay in the city is a period of weak social control for migrant women and a few behave in ways considered to be counter to 'village ethics'. These are:

– unwanted pregnancies: several young migrants return to the village with unwanted pregnancies or venereal diseases. The places where migrants group after their work are places for the young women to sing and dance in the presence of their boyfriends, who are small traders, also migrants. These places are called *alzanaye*, a Zarma term that means 'festivities' and, in other words 'live youth to the full'. The migrant girls who go to these places easily become pregnant and thus marginalised because of various sociocultural and religious reasons;

– unexpected divorces: the mobility of women in the city is a regular cause of divorce, especially in young couples. According to the persons interviewed, it is more often women who ask for divorce. The temptation of life in the city may cause disdain for village life and the first thing to do to be able to go back freely is to ask for divorce. Some take lovers in the city and finish by ending their marriage in the village. Other find that their husbands are too close to traditions and no longer match their taste. In these cases, they decide to refund their dowry with their own money, or have it refunded by their new lover.

> 'My nephew, who lives in Arlit married a migrant girl. When he came to Bonkoukou to take his wife to Arlit, he didn't find her. His bride was in Niamey. So her father decided to go and get her. But he came back without her. He said that she had hidden and he couldn't find her. My nephew waited for a few days and his wife still did not want to come back […]. She didn't want her marriage any more. People say that she has a job and earns 50,000 CFA francs per month and prefers to divorce rather than lose her job. My nephew did not want to go back to Arlit without a wife because in this case he would be the laughing-stock of his friends. So in the end he married another girl and went back with her' (interview of a women from the village of Bonkoukou, November 2013).

The rare occasions when men ask for divorce in in the case of married women who become pregnant or flaunt lovers;

– refusal to carry out certain household tasks in the village: when they return to the village, some migrants refuse to do work that requires a physical effort or that is carried out in the sun: pounding, drawing water or looking for firewood;

– refusal to return to the village: although not very common, there are cases of migrants who decide not to return to the village after a long stay in the city. They get married there and no longer return to their home village.

In addition to these forms of breaking with local values in the district, female migration is a barrier to the schooling of girls. Indeed, several girls leave school to enter the seasonal migration cycle.

> 'Female migration is a dangerous phenomenon for the school. Here, in Balley, we note the abandoning of school by girls from the second year of primary school onwards. But the largest numbers concern the fourth and fifth years of primary school. In all, 17 girls have abandoned school this year. This is serious! Because of migration, we rarely have girls who go on to secondary education. They all want to go to Niamey, and their parentscan't do anything because they profit from the situation themselves […]' (a teacher in the village of Balley, November 2013).

The features above show clearly that even if it seems to be an alternative giving households the possibility of obtaining resources and the migrant the possibility of emancipation, female migration in the administrative district of Imanan causes real problems. This applies both to certain migrants (divorces, pregnancies, diseases, refusal to return to the village, etc.) and to the community in general (change of family relations, removal of girls from schools).

Conclusion

Today, female migration in the rural district of Imanan is a key component of the way of life of women. It contributes to covering the food and clothing requirements of households and helps girls to assemble their trousseaux that were previously purchased entirely by their parents. Low incomes and the small opportunity for paid jobs is the foundation of parents' withdrawal from performing some of their social roles. This gives practical legitimacy to female migration, and especially the migration of girls, that now affects several households in the district.

Only two socio-professional groups are still little concerned by migration: the Garrassa, families of craftsmen for whom working with leather and braiding are important activities that generate income, and the Surgu, the group with customary power and the most fertile land. Four main features can be observed after this study:

– even though migration goes back a long way, that of women is recent in the district of Imanan and has increased in recent decades;

– the scale of migration can be seen as a both individual and collective response (it also involves other members of the family) to the economic difficulties of households;

– migration to the city of Niamey is gradually becoming a stage in life (an obligatory period) for many young women in the Imanan;

– female migration causes local family disturbances, in particular because of the weakening of parental and marital authority (increased autonomy for women).

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Chapter 16

Political changes, landholding dynamics and socio-economic reconstruction

Imanan administrative district (Niger)

Abdoulaye Mohamadou
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Introduction

The Sahel region is emblematic of the dynamics of the links between society and the environment whose adaptation to climate change—a very fashionable theme today—is one of the signs. Indeed, drought, the degradation of natural resources, poverty, etc. have structured the living and survival strategies of Sahel populations since the 1970s. This interaction between people and the natural environment is not reduced to impacts and adaptation strategies. It also affects the dynamics of social relations and in particular as regards land and natural resources. Jean-Pierre Jacob (2007) highlighted the link between power and land in traditional African societies. In most of the latter, the group or lineage that holds land capital also controls political power and reinforces this by using land as a negotiation weapon in its links with the other social groups—both native and immigrant. Local political configurations also affect farming systems and land rights. Indeed, social relations centred on production are linked with social status and social division of labour. These relations are changing, in particular because of the ecological conditions that in the Sahel are linked with the effects of climate changes (droughts, impoverishment of land, degradation of plant cover, etc.) on land and natural resources. This is the case for example of rights to trees; these have changed in recent years, with tendency for their individualisation.

The aim of this work is to analyse the economic, spatial and political changes that have occurred in the Imanan administrative district. They are set in the overall context of the construction of the Nigerien state and ecological and economic changes.

Imanan administrative area: a nomadic/pastoral area in an agricultural zone

The Imanan area became a ‘commune’ in 2004 within the framework of the new territorial division linked with Niger opting for complete decentralisation. With an area of 506 sq. km, it is one of the smallest districts in Niger. The population is estimated to be 36,665, that is to say density of some 72.46 persons per sq. km. It has 45 administrative villages, with the main one being Bonkoukou.

The district is sited in a fossil valley (locally called *dallol bosso*) set between two plateaux, one being to the north-west and the other, called Fakara in Zarma, to the south. The features of the three areas are fairly contrasted with regard to both soil and vegetation and population densities and activities.

The valley consists of bottomland with sandy soil that is increasingly leached as a result of erosion by water and wind and over-exploitation for crops and grazing. Groundwater is at a fairly shallow level, varying from 3 to 7 metres. This available water has made it possible to grow market garden crops and especially potatoes, now the main cash crop. According to the farmers, vegetation has practically disappeared as a result of demographic and landholding pressure. Areas of *Acacia albida* and doum palms can be seen in places. While the former is used as fertiliser in fields, the latter for a significant source of income via the sale of products made from them. A farmer in Amassaghal said that ‘a stand of doum palms is better than two cows—it provides the sauce for the week.’

Stands of doum palms are larger in the southern part of the district, in the zango (Tuareg village) of Kochlane as the soils are clayey.

The two plateaux are glacis zones but small areas of bottomland are also to be seen. Occupation of that in the south of the district followed upwards shift of the agricultural front, while that in the north-west has been farmed for longer because of the Zarma farming population. The land on the plateaux gives better crop yields that the valley land that is impoverished by several decades of use. The plateaux are also used as grazing land and transit zones for livestock farmers in the district and from other regions, including transhumants arriving from Benin and Nigeria.

Imanan rural district has three permanent ponds and four or five semi-permanent ponds, depending on rainfall. The permanent ponds are generally developed, stocked with fish and managed within the framework of intervention by the state and by development projects. This is the case of Tashi pond where a sill has been built, leading to the appearance of new activities (market gardening and fishing) and a change in the rules of access (Mohamadou and Moussa, 2013).

Other environment operations by the state and its partners are focused on the protection and restoration of the plateau land. This often non-cultivated land belongs to local communities. Half a dozen sites have been listed in the district. When there is vegetation, they serve as grazing land for the surrounding villages. However,

Table 1.
Rainfall at Bonkoukou from 1965 to 2011.

Year	Rainfall recorded (mm)	Number of days of rain
1965	**595.5**	**34**
1966	**307.9**	**22**
1967	**454.3**	**26**
1968	**454.3**	**22**
1969	**339.5**	**27**
2006	**608.9**	**31**
2007	**413.6**	**28**
2008	**487.8**	**40**
2009	**451.4**	**34**
2010	**535.8**	**36**
2011	**433.5**	**30**

Source: Bonkoukou meteorological station.

these land recovery operations are limited and cannot reverse the overall trend for the degradation of land and the environment. However, it is noted that farmers increasingly used assisted natural regeneration for certain species of economic interest—especially doum palm and gao (*Acacia albida*).

Examination of precipitation records for the last 40 years shows that rainfall has not really changed.

The rainfall data show that precipitation was great in the 2000s than it was towards the end of the 1960s. In addition, it is seen that the number of days of rain was greater during the 2000s than during the 1960s. These data contradict the perception by the populations, who consider that it does not rain enough. But the reasons for this difference should doubtless be sought in intra-annual variability of precipitations, with longer, more frequent drought periods, and above all in the combination of several factors that have a negative effect on plant development and yields. Even if the precipitation figures are the same, the soil no longer has the same degree of fertility and new insect pests and diseases have often appeared. Farmers say that they came with the droughts and climatic variability.

Mobility and sedentariness in an area undergoing degradation

Through the combination of political, ecological and economic factors, the way of life and farming systems have undergone marked changes in the Imanan.

The conquest of the area by the Tuaregs

The majority of the population of the Imanan district consists of Tuaregs and local political power is held by this group via the chiefdom of the area. When the Tuaregs arrived at the beginning of the 19th century, they found existing populations of Zarma and Hausa (Goubé and Soudjé). The Tuaregs came in successive waves, first warriors and then groups. The first consisted of Iwillimenden and Lissawan whereas the second were Kel Esuk, craftsmen, Iboghileten, etc. The Tuaregs came from the Tahoua region. About seven village cores existed before the colonial period: Diguina, Bonkoukou, Koshlane, Jami, Dakfao, Shett and Shiwil, where the noble Tuareg families had settled with their dependents (GUILLAUME, 1974).

The Tuareg social system in the Imanan was very stratified before the arrival of French colonists. Indeed, there were noble families, dependents and free communities.

The dependents, mainly domestic slaves, freemen, craftsmen and the Kel Esuk farmed the land that the aristocratic families placed at their disposal. Domestic slaves worked on farms under the direct control of their masters while the other groups had fields awarded by the aristocracy and for whom they reserved part of the crops. The Zarma, Goubé and Soudjé, had dependent relations with the noble Tuareg families. After each harvest, a tithe was given to the head of the noble family as a sign of allegiance.

> ‘At the end of the harvest, or today, our concession, all these villages, they must bring to us here all the bundles that they take as a tithe or something else. But today, it’s the head of the canton that they bring, but not everyone. The *zakkat* that they take is for him. That’s something that exists even today. When things go well, what the chief has can fill granaries. […] In the time of chief Bizo—he died in 1952—when he reigned he just sent his *dogaris* [guards] to the zones where gifts of millet had been reserved for him; the granary was there. There could be 10 granaries’ (H. S.).

After migrating to the Imanan, the Tuaregs gradually became sedentary and combined crop and livestock farming. The families had long ceased transhumance and the livestock was entrusted mainly to Tuareg or Peul herders who took it to grazing areas during the rainy season.

The first Tuareg chief married the daughter of a Zarma chief, opening the way to marriages with different local chiefs. This choice deeply marked Tuareg society in the Imanan. After intermarriage with the sedentary people, most of the Tuaregs today have dark skins and the latest generations have lost the Tamasheq language in favour of Zarma and Hausa. It is actually possible to talk in terms of Zarma-speaking Tuaregs. However, turbans are still worn by adult nobles. Although male Tuareg nobles can marry Zarma, Hausa and former dependents, a marriage between a former dependent and a noble Tuareg woman is extremely rare

Senior persons of low origin also marry Zarma and Hausa women and thus form alliances with their wives’ groups.

We collected numerous versions of history of settlement by the Tuaregs. The first Tuaregs very probably arrived alone, fleeing the wars in the Tahoua region. They then married and captured or purchased slaves. Whole families subsequently joined them and placed themselves under their protection.

The Tuaregs forced the Zarma to leaves their villages (Shet, Duiguina, Bonkoukou, etc.). The Zarma migrated to other regions to the west and south. The present Zarma villages on the western plateau became part of the administrative district in 1920 and those of the southern plateau were founded later.

The main village of the zone has a Hausa district, inhabited by former travelling vendors from the Tahoua region. The Hausa Soudié and Goubé became part of the Kurfey district.

The re-drawing of the boundaries by the colonial administration

After pacification, the colonial administration set up district chiefdoms for both the sedentary population and nomads. This special treatment, whereas elsewhere nomad chiefdoms are called groups (organised more on a tribal basis than on place of residence), shows the specific nature of the territory of the Tuaregs of the Imanan and the Taghazar (another Tuareg canton in the department further south) through their isolation in the agricultural area and their fairly sedentary way of life.

The colonial administration reduced the area of the Imanan Tuaregs to the benefit of the Tondikandia Zarma canton in the south and the Kurfey Hausa canton in the north. Some historical Tuareg centres were removed, such as the village of Shet, where the Tuaregs first arrived and which was made part of the canton of Kurfey. This decrease in area concerned above all the Dallol valley, an agricultural area par excellence. The nomads were awarded above all the plateaux most suitable for livestock.

> ‘Our canton is a small one. The white men shrank it. You know that when the white men arrived the Tuaregs created problems by wars. Something that has been forbidden. So to master them they were squeezed on each side, the canton was reduced on each side and they were given a small area. When you leave here, it’s hardly 7 or 8 kilometres to the boundary and when you go in the direction of Filingué it’s the same thing—less than 12 kilometres. The district is long from east to west, formed by plateaux, but not in the south to west in the valley. Our fields ended up on the other side, but who could say anything during the time of the white man?’ (A. I.).

The frontier between the canton of the Imanan and that of Tondikandia remains to be defined and landholding litigation is still in progress today. The canton of Tondikandia also considers that historically the north-west plateau is not part of the Imanan but was made part of the canton by the colonial administration when the cantons were created in 1920.

The former head of the canton of the Imanan (1952-1974), former member of parliament and minster during the presidency of Diori Hamani (1960-1974), tried to use his influence to move the frontier but did not succeed. Under General Seyni Kountché (1974-1987), from the canton of Tondikandia, his elder brother who was head of the canton unilaterally annexed land from the canton of the Imanan. Ahmed Sada, head of the canton at the time, refused to accept this decision. He was revoked by order of General Kountché. Others mentioned his behaviour and youth to justify his dismissal. The opponents of the present head, appointed by Seyni Kountché, is said by his opponents to be an ally of Tondikandia, accounting for continuous intrusion by people from this canton in land in the Imanan.

Border disputes between the two cantons are very frequent, especially on the western plateau. Numerous cases are waiting for the courts according to the representative of the head of the canton of the Imanan.

The release of slaves and new procedures for access to land

The colonial administration took another decision that upset land use, the farming system and the control of land and access to it. Indeed, the measures taken for the freeing of slaves and their access to land—with this liberation decided by the colonial authorities after the 1916 Tuareg revolt, in which the Tuaregs of the Imanan were involved—resulted in new occupation of land and new land and economic dynamics.

Some former domestic slaves went far from their masters and founded new villages, while others remained in the village as farmers. This is the case of the village of Diguina, where the nobles still live alongside their former slaves. The latter farm the land and no longer pay a tithe but cannot sell, lend or give the land without the permission of their former masters. They just have usufruct and still have a relation of dependence on their masters.

Freemen (Ighawelan and Iboghiliten) farmed land loaned by noble families to whom they paid a tithe. After decisions by the colonial authorities, the freeman took over the land. They then increased their land capital by new land clearance, mainly on the southern plateau, and also by purchases of land from the Zarma.

Situations are very contrasted according to the part of the administrative district, the status of the former dependents and the attitude of the aristocratic family. In the villages in the north-east of the district, a stronghold of the aristocracy, the nobles maintain control of the land. In the south, with the exception of the Kochlane Touareg, all the villages were founded by freemen who own the land. The Tuaregs had a weaker hold on land in the centre and the north-west. The Bella villages (names of former slaves in Zarma) are concentrated mainly in the latter zone. During the reigns of Akkomar ag Yogo (1905-1932) and Bizo ag Wadéghun (1933-1952), numerous former slaves obtain land by a donation or by clearance in this part of the canton that used to be occupied by Djerma. The colonial administration unified the Tuareg principalities and chose a chief in one of the aristocratic lineages. All vacant land then became part of the estate of the chiefdom of the canton. But the aristocratic subgroups gradually regained autonomy. The present chief of the canton has little hold on the land of other aristocratic families, especially in Diguina, Kochlane and Shiwil. Thus Shiwil and Kochlane have more control of the southern plateau, Diguina has more in the north-east and the chiefdom (Feraw) is more affirmed in the management of the western plateau.

Thanks to control of land, former dependents have gained economic autonomy. They draw an income from farming and from migration rent, whereas the nobles became poorer for want of labour. The present land occupation map for the administrative district shows that the villages of former dependents are more numerous by far that those of the aristocratic lineages of the Tuaregs and other ethno-linguistic groups. This also shows the demographic weight of salves in this society.

The Tuareg aristocracy has thus lost and important lever for domination but has kept a large land capital that ensured it a clientele among the former dependents. Its control of local power also made it possible to act as negotiator with the colonial administration and, later with the post-colonial state. It invested in education by sending the children to school (the colonists had founded schools for the children of the chiefs) in contact with nomad chiefdoms. The first pupils worked for the colonial administration and, from the 1960s, officials of the Tuareg aristocracy of the Imanan were elected to parliament or appointed to senior public service positions, with ministerial posts in particular. Among the latter, Mouddour Zakara is the best known and played an important political role at the national level. In spite of its subservience to the administration, the aristocracy has kept customary powers, has substantial land capital and has gained significant cultural capital. It thus has large resources in spite of its small demographic weight.

From grouped to scattered settlements

The liberation of slaves resulted in the founding of numerous villages that were previously farm hamlets. After several years of cultivation, the land in the valley where the population was concentrated became impoverished. Several strategies were used to address the situation. First, plateau land was used for crops to counter-balance the poor yields of the valley land. Those who could not have plateau land became poor. Systems for loans from former masters were used increasingly. But the most spectacular innovation has been the dismantling of certain villages with the farmers then settling in their fields. This is a soil fertility management strategy. Families set up their straw huts on degraded parts of the field to fertilise the soil with domestic waste and manure. Animals are tethered to posts in bare places. The positions of the huts and the livestock are changed every two or three years according to the fertility levels in the different parts of the farm.

> ‘Here, every head of a family has settled in his field. This is to enrich our soils that have become very poor over a period of time. But we haven’t always been scattered like that. Our families were from Shet and then the grandparents migrated to Takarwet (Tassi) and that is where everyone has settled in their field with the livestock to at least make manure for the field’ (head of a Toulouwa village).

> ‘Before, the chief was here but about 30 years ago he left the main village and settled in his field 5 kilometres from here. Several villagers have done what he did’ (representative of the Tillobi village chief).

The core village only house a few families, in particular those of the heads of the village and certain notables, and the socioeconomic infrastructure (school, health centre, grain bank, etc.). Some heads of villages, such as that of Amassaghal, have settled in their fields.

The population groups of the Imanan are of nomad origin and have conserved mobility as a strategy for land and fertility management.

The return to valley land: the development of market garden crops

The introduction of potato growing in the 1970s has played an important role in the evolution of farming systems, survival strategies for the population and increasing household income. The Bella Kochlan village chief summarises the situation as follows: ‘If you don’t grow potatoes, you’ll die’.

The development of the growing of potatoes and other market garden crops such as bell peppers, tomatoes and even *Moringa olifera*, has generated renewed interest in valley land. Not all the soils in the valley are suitable for market garden crops because of the depth of the groundwater and the nature of the soil. Not everybody who has suitable soil has the means to use it. New transactions have become established. Members of a farming operation or their relations combine to finance potato growing. The investment is for the well and agricultural inputs. The latter are supplied on credit by suppliers at the small market in Niamey who also purchase the potato crop. Two traders from this market even purchased land for potato growing in the village of Bella Koira on the outskirts of Bonkoukou.

The introduction of market garden crops has resulted in widespread use of fencing to protect the fields. The wealthier farmers often use wire netting and those with less funds use dry hedging. Development projects have contributed to increasing this trend. Some farmers combine livestock and orchard fruits with market garden crops.

Potatoes have led to phenomena of social differentiation between farmers that run through all social groups. Large potato growers form a small local bourgeoisie. They have set up a cooperative to defend their interests. The president of the cooperative has been the regional president of the chambers of agriculture of Niger (RECA). He is also a local political leader.

The district land commission as an institutional innovation

Within the framework of rendering landholding secure, the permanent secretariat of the Rural Code, which is the official landholding regulation body, has set up a commission in Imanan administrative district. The aim is that of formalising land transactions and enabling farmers to hold land deeds.

Table 2.
Land transaction agreements drawn up from 2006 to 2014.

Category	**Number of documents issued**	**Places concerned**
Certificate of customary possession	15	Shiwil and Bonkoukou
Land sale certificate	38	Fakara Plateau
Certificate of donation	01	Bonkoukou
Land loan contract	12	The entire administrive ditrict
Contract for customay pledging of land	02	Bonkoukou
Land rental contract	02	Bonkoukou
Total	**70**	

Source: Bonkoukou distric land commission.

The data in Table 2 are certainly not representative of all the land transactions in the district of Bonkoukou. It is known that many deals are done between farmers without being declared. However, it can be observed that certain transaction are substantial and show certain changes. There are a large number of sales of land ion the southern plateau (Fakara). The Zarma sell their land to the Tuaregs, particularly from Amassaghal. According to the permanent secretary of the land commission, they sell because they need food. Requests for customary holding are by farmers who draft loan request files. This is a requirement of credit institutions. Contracts for loans of land are requested by persons from the administrative district and landowners who live outside the district—often abroad. For them it is a measure of security of their landholdings.

Dependents: from economic autonomy to political representation

The colonial administration allowed former dependents to gain freedom and above all economic autonomy. However, they were still dominated politically as the canton chiefdom was the dominant institution in the local political landscape. Heads of villages remained subservient to the head of the canton, who had great power in tax collection and the management of landholding conflicts. A large number of former slaves obtained land by donations or by clearance authorisations awarded by successive heads of cantons.

Democratic opening in the 1990s enabled the former dependents to have new institutional mobilisation frameworks with a view to access to the public spaces obtaining political representation. The political parties and civil society organisations provided this opportunity. The former slaves fought massively in an antislavery association called Timidria. The objectives of the latter were to fight slavery practices and defend the rights of former slaves. This position led militants in the Imanan to enter a struggle for position in the local political arena.

There were two main political parties in the Imanan in the 2000s: the *Parti nigérien pour la démocratie et le socialisme* (PNDS-Tarraya) and the *Mouvement national pour la société développement* (MNSD-Nassara).

The PNDS-Tarraya is above all the party of senior aristocrats, some of whom form part of the national management of the party. All the leading aristocratic families in the canton joined the PNDS, with the exception of the one that held the chiefdom are preferred to remain in the state party, a strategy much used by the traditional chiefdoms to avoid offending the power if which they are the final local link in the chain. In 1998, after General Baaré (who gained power by a military coup d'état in 1996) founded the *Rassemblement pour la démocratie et le progrès* (RDP-Jamaà), a proportion of the senior aristocracy who were with the PNDS joined the new party for questions of leadership. The same people later became affiliated with the MNSD Tanja cale to power in 2000 and who wife is from the village of Diguina, one of the major strongholds of the aristocracy. The MNSD section in Bonkoukou is run by an aristocrat from the village. The senior aristocrats brought part of their dependents with them and especially those who lived with them.

The MNSD attracted the Zarma and the former dependents. An important figure in this community, Torda Hainikoye, a former senior officer and former prefect, president of the Niamey urban community and former private secretary of President Tanja handled the establishment of the MNSD in his group. He became the first mayor of the Imanan administrative district in 2005. Issouf Amouane, the vice-mayor, was the brother of the head of the canton, with the latter being part of MNSD. A former commander, the vice-mayor was a product of the state-party and naturally joined the MNSD. Aristocrats and former dependents are members of the MNSD and have different legitimacy and projects.

In his management of district council, the mayor used the resources of the district and his partners to invest in the former dependents' villages. Land management remained under the control of the head of the canton, which used this for its own interests (MOHAMADOU and MOUSSA, 2013). Court cases dragged on, with suspicion of corruption of those involved.

The MNSD split in two in 2009 with the founding of Lumana FA, the new party of Hama Amadou, former president of the MNSD in conflict with President Tanja whose prime minister he had been but who finally sent him to prison. Many members of the MNSD in the Imanan joined the new party. These were mainly former dependents who considered that local MNSD officials did not defend their interests, especially because of the arbitrary manner in which they were victims of land management.

Indeed, the aristocrats, including those belong to the present chiefdom, use land as a means of exerting pressure on the former dependents. They threaten to take the land given to their grandparents from all those who are not members of their party.

Land censuses are carried out by the aristocrats with the aim—according to one of them—of reminding the former dependents that they are not owners, and thus ensure their landholdings. A former dependent from Diguina confirmed that the land they farmed was still under the control of the aristocratic families. This also explains why sales of the valley land controlled by Tuaregs are very rare. The former dependents know that there will be a reaction from the former owners. Land sales mainly concern land on the plateau, where part of the land belongs to Zarma.

The political issues have generated a certain insecurity with regard to landholding in the district. To this is added the renewal of interest in the valley land. An increasing number persons from the area with financial capacity can obtain funding for projects and bank loans.

Conclusion

Examination of the evolution of Tuareg society in the Imanan and its territory for a period of nearly two centuries reveals deep-seated political, economic and ecological changes. Originally nomadic herders, the Tuaregs of the Imanan became sedentary and switched to crop farming while remaining ready to move their livestock and homes when necessary. The latter strategy is a response to the degradation of arable land. A particular type of agropastoralism thus emerged with scattered dwellings in order to better manage fertility and livestock. Colonial intervention favoured the emergence of new landholding dynamics and the gaining of economic autonomy by former dependents. The latter became scattered over the whole area of the canton, founding new villages and clearing new land. Less than a century later, the valley land was entirely occupied and had become impoverished, obliging farmers to farm the plateaux. The 1970-1980 economic slump accentuated this degradation of natural resources. Potatoes became the main lever of the local economy. The crop has increased farmers' incomes significantly and caused fractures in the various social groups while enhancing the economic autonomy of young people.

The valley land that had become unsuitable for rainfed grain crops is recovering a certain value thanks to market garden crops and orchard crops. It is crystallising the political struggles between the various stakeholders and leading to new land transactions.

This study shows the interactions between society and its environment. Climatic and environmental change has en influence on economic, social and political changes and vice versa. Growing potatoes is an adaptation strategy to counter-balance the poor yields of rainfed crops. It is possible because of shallow groundwater and demand in Niamey. Development of the crop has changed social relations centred on the land and in households.

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Part IV

Adaptation of farming systems, innovations

Harvesting and storing heads of millet in the Niakhar region (Senegal).

Introduction

Richard Lalou

In the first decade of the 21st century, adaptation of humans to climate change has suddenly become a question for public debate and has been regarded as a focus for scientific research, an issue in technical/political planning at local, national and international levels and a topic for promoting public awareness (IPCC, 2007; Smit *et al.*, 2009). In its 4th Synthesis Report, the Intergovernmental Panel on Climate Change (IPCC) explained this interest by showing that the reduction in greenhouse gas (GHG) emissions would not stop all climate change impacts, some of which are already being felt (Parry *et al.,* 2007). Past and current emissions will have inescapable consequences tomorrow due to their very long atmospheric lifetime. Adaptation measures are therefore urgent and necessary in addition to efforts for reducing GHG emissions.

Generally, adaptation aims at reducing vulnerabilities of natural and socio-economic systems to face climate changes at least cost. According to the IPCC's usual definition, 'adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC, 2007: 27). Thus, the notion of adaptation is opposed to that of mitigation as adaptation operates primarily at the local level and its benefits in terms of vulnerability reduction are obtained on a shorter term basis. In contrast, it is more difficult to estimate the impacts of adaptation actions on the vulnerability of people, societies and territories, as there is no measurement akin to carbon footprint (ton CO_2 equivalent) to quantify GHG reductions. Finally, the IPCC's understanding of adaptation is very specific with no reference to its complexity, although this concept was shaped for other paradigms on the basis of extensive interdisciplinary research.

Adaptation is thus considered through climate change alone and adaptation responses only aimed at mitigating the impacts of a climate shock or using the benefits of a climate opportunity. But we know that the overall processes leading to changes in societies and enhancement of people's quality of life can also contribute—directly or indirectly—in reducing the vulnerability of social systems to climate change, without necessarily causing major adverse effects on the natural environment and the climate (ADGER *et al.*, 2009; MOSER and EKSTROM, 2010).

There is nothing new about individual or societal adaptation in the history of humanity either as an empirical experience or even as a theoretical construct. Humans have faced precarious resources and living conditions resulting from climate change for a very long time, in particular by developing technical innovations (irrigation, breeding resistant crop plants, weather forecasting, etc.) and socioeconomic aspects (including insurance covering natural catastrophes). Many authors, however, have argued that it is not so much a question whether human societies can adapt—in absolute terms, they demonstrate this every day—but that of proving that past adaptations can foreshadow capacities that will be useful to future generations in adapting to tomorrow's global changes. Indeed, adaptations made in the past cannot be compared with those that will have to be provided in the future to the impacts of climate change whose scale, intensity, speed and variability are totally unprecedented (ADGER and BARNETT, 2009; ADGER *et al.*, 2009; BERRANG-FORD *et al.*, 2011). The adaptation of human societies to climate change thus involves the quasi-consubstantial question of the limits to adaptation.

Scientists often resort to the concepts of limits or barriers and also constraints or stress almost interchangeably, although their meanings differ considerably. While barriers generally suggest constraints or stress factors that can be surmounted, the limits—in line with the IPCC's understanding (IPCC, 2007)—refer to insuperable obstacles, thresholds beyond which human activities, land use, ecosystems and species cannot be maintained, even in a modified form. Ecological and physical constraints thus jointly set the limits of adaptation. The latter can take various forms, ranging from ecosystem thresholds (habitat, biodiversity, functioning), beyond which adaptation (resilience) is no longer possible to limits of biomes and to the exhaustion of resources (PARMESAN and YOHE, 2003; FISCHLIN *et al.*, 2007; USGS, 2009). Thus, the limits of adaptation are defined as exogenous to the social system, like physical and ecological constraints.

The other factors that oppose adaptation, but without ruling it out entirely, are usually barriers that come from society and its interactions with nature. Adaptation is not solely a necessity fully assessed by international experts and required by external natural conditions but is also a choice made by individuals and communities and based on: i) scientific knowledge and collective experiences of danger; ii) individual and collective norms and values that shape ways of thinking and acting; iii) economic, sociocultural and symbolic costs of adaptation; iv) and the purpose of adaptation (a return to previous equilibrium or a stage towards new technical-economic progress). These subjective barriers that change strongly according to context and history partly overlap the factors generally raised by 'adaptation capacity' and 'vulnerability'. For both individuals and communities, the low level of economic resources, the limited access to technology and the lack of skills are clearly factors that hinder adaptation. Many researchers even consider that they account for ongoing lack of adaptation in low-income countries, particularly in Africa (ADGER *et al.*, 2005a and b; SMIT and WANDEL, 2006; HULME *et al.*, 2007; MOSER and EKSTROM, 2010; DOW *et al.*, 2013).

As a rule of thumb, adaptation strategies should include three levels of uncertainty with regard to: i) the future climate; ii) climate change impacts on natural and socio-economic systems (MEEHL *et al.*, 2007); and iii) future benefits of an adaptation process undertaken today (MAGNAN, 2013). Each of these uncertainties can become a barrier in the adaptation process (problem identification phase and action planning stage) (MOSER and EKSTROM, 2010). These uncertainties are all the more high and determining for action that adaptation is a local phenomenon by definition, and projections of the climate and its impacts are provided at continental or regional levels. Furthermore, uncertainly related to long-term forecasts is more important in Africa than anywhere else in the world due to the lack of reliable and sufficient meteorological data. Admittedly, uncertainty justifies focusing on reactive rather than on proactive adaptation all around the world. Several authors have shown that the economic, social and environmental costs of climate change impacts will necessarily be higher if adaptation measures are not anticipated (STERN, 2006; PARRY *et al.*, 2009). However, reactive adaptation is by far the most common category in both poor and rich countries (ADGER *et al.*, 2003; AMUNDSEN *et al.*, 2010). It is implemented after an extreme event has occurred and therefore does not involve a proactive response. Likewise, the benefits of reactive adaptation are often immediate or short term—another feature that limits potential maladaptation (when adaptation increases the climate change vulnerability of populations and territories) or avoids adaptation with regret (when the environmental risk that the adaptation is designed to counter does not take place).

Several recent studies on adaptation practices and their processes have shown that the capacity of a system to respond effectively to climate change and variations does not depend solely on knowledge that reduces uncertainty and increases awareness, or entirely on economic and technological development. It is also determined by social norms and cultural values and rules (BROOKS et *al.*, 2005; NAESS *et al.*, 2005; FORD *et al.*, 2006; COULTHARD, 2008; ADGER *et al.*, 2009). Adaptation is a local process and depends on the social and cultural context in which it is constructed. Therefore it varies between individuals, within communities and between communities, territories and countries (O'BRIEN *et al.*, 2006; IPCC, 2007).

Social institutions and customary law often govern access to and control of resources at community scale. According to E. OSTROM (2005), an institution is the 'rules' that govern systems of beliefs, organisational structures and the practices of a community. These rules generally include land rights, rules for the management of common fallows, closure to grazing animals, access and management rules for common resources, etc. Likewise, caste, ethnic group and gender in certain societies are institutions that generate norms, values and rules that may affect the behaviour of individuals when they are faced with stress or shocks. When they are well established and recognised by all, these institutions allow communities to make better responses to social and environmental changes. But when the rules, whose legitimacy is often based on tradition, can no longer handle the changes in ecological and social systems, they may become norms that are real barriers to adaptation. This applies to adaptive responses used repetitively and in conformity with culture and tradition but that may prove to be inappropriate in the face of future environmental changes (maladaptation) and unsustainable (JONES *et al.*, 2010; JONES and BOYD, 2011; NIELSEN and REENBERG, 2010). In other words, institutional rigidity may sometimes limit the innovation capacity of sociosystems faced with climatic and environmental shocks.

In West Africa, as elsewhere in the world, the adaptation of agriculture to climate change is not a new idea. Small farming in Africa is mainly rainfed and strongly subject to climate change and variability, making it necessary for farmers and their families to implement adaptation strategies to maintain their standard of living and production (of foodstuffs, forage, firewood, construction materials, etc.) Even without economic and technical resources, African farming populations are thus neither necessarily nor completely vulnerable when faced with threatening, harmful events. But their responses must also fit in with all the constraints, uncertainties, barriers and limits that have been listed and that reduce their scope for action. This results in minimal 'survival' adaptations that are not always effective and are rarely sustainable.

The last part of the book is focused on farming adaptations and we have considered four different agricultural pathways in three West African geoclimatic contexts (Benin, Niger and Senegal). As is seen in Chapter 4, climate change takes various forms in the three study areas: the warming trend can be seen everywhere but rainfall displays singular patterns. In northern Benin, precipitation has been stable at around 1,200 mm per year since the early 1990s. In central Senegal, rainfall increased rapidly at the end of the 1990s, reaching an average of more than 600 mm per year in the last decade. Finally, although rainfall recovered in southern Niger after the great drought, the cumulated totals have decreased significantly over the last ten years. Adaptation by farmers is clearly at a local scale, responding to the meteorological conditions of the moment while taking into account the constraints and opportunities of the environment. Senegalese farmers thus profit from more abundant, longer rainy seasons by growing long-cycle cereal varieties (Chapter 18) while those in Niger make up for the shortage of rainfall and the small yields of rainfed crops by growing counter-season crops and using underground water (Chapter 20). But the adaptations described in this part of the book are not all a response to climate logic alone. Farming innovations such as potatoes in Niger (Chapter 20), cashew nuts and soya in Benin (Chapter 17) and cattle fattening in Senegal (Chapter 19) tend rather to draw a benefit from the sales opportunities created by the development of the urban market. But all these adaptations—related to climate change or not—reduce the vulnerability of families, especially as regards the climate. It is reminded here that counter-season activities such as fattening livestock and growing potatoes tend to settle farmers in their area and reduce seasonal migration of labour whereas the drought years could trigger rural exodus.

All the examples of adaptation examined 'confirm the rule' in a way: the adaptation of small farmers in Africa is generally spontaneous (with no substantial dialogue and coordination between the stakeholders), reactive and involves little risk. The return of more abundant rainfall in Senegal has enabled farmers to return to an old (pre-drought) agrarian system, that is to say traditional practices that are less risky practices because they are culturally acceptable and economically viable. They thus reintroduced long-cycle millet that had practically completely disappeared between 1970 and 2000 (Chapter 18). Likewise, the virtuous combining of crops and livestock that had been very difficult during the drought period reappeared with the development of cattle fattening. This not only allowed a return to the old method of transfer of fertility but also has been found to be a richer and better source of organic matter than traditional extensive cattle farming (Chapter 19). In other words, adaptation did not hinder the potential for changing the agrosystem. While conserving the guiding principles that ensure its sustainability (the combination of crops and livestock), an innovation has been incorporated in the farming system that improves its performance with regard to the conservation of soil fertility.

It can be said more generally that all these adaptations show how farming societies in Africa manage to adapt to global changes but without becoming too resistant to disturbances—that is to say incapable of change—in the face of shocks that are as random and creative as destructive. When so required by ecological, social and political constraints, this means in-depth changes to the system, in the same way as what could happen at the global scale with a transition to low carbon economies.

Adaptation thus requires resilience and the ability to change, that is to say a dynamic capacity of the system to rebuild itself differently within a new area of balance.

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Chapter 17

Innovation in rural West Africa
What changes in farming practices?

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Introduction

In rural parts of West Africa, farming is carried out in a context of poverty and farmers who already suffer many kinds of stress must face up to climatic changes. Here, adaptation to these changes has become a major research theme in recent decades.

From the political angle, the concept of adaptation to climatic changes is unambiguous: it consists of using appropriate policies to strengthen the capacity of the most vulnerable populations to respond to the challenges formed by climatic changes (UNFCCC, 2007). The International Panel on Climate Change (IPCC) defines adaptation as a change in farming systems in response to climatic changes or variability in a context of interacting social and environmental changes (Adger, 2007). Guided by political objectives, adaptation is a direct, intentional response imposed by climate change that is external to human and natural systems.

The adaptation of agricultural practices to climatic changes is the subject of considerable empirical literature. Measuring adaptation to climatic changes involves the establishment of a relation of cause and effect between a stress, the climate and an adaptive response to this stress. The climatic cause of adaptation seems obvious in certain contexts, such as arid environments (Mortimore and Adams, 2001). However, identifying the response to a climatic stress is often difficult. Climatic phenomena seem to form a component that interacts with other stresses and climate is never the sole factor of an adaptation (Mertz *et al.*, 2009); Berrang-Ford, 2012; Huq and Reid, 2004; Smit and Wandel, 2006; Kristjanson *et al.*, 2012).

This makes it difficult to render the concept of adaptation operational with regard to climatic changes.

One way of rendering the IPCC stimulus-response model operational is to take the perception of climatic stress into account. This method is based on the idea that stakeholders must necessarily perceive the risk before taking action (VEDWAN and RHOADES, 2001; GROTHMAN and PATT, 2005). Numerous studies thus use measurement 'in two stages'. based on this link between perception and adaptation (MADDISON, 2007; GBETIBOUO, 2009; BRYAN *et al.,* 2009; OUÉDRAOGO *et al.,* 2010; FOSU-MENSAH *et al.,* 2012; SILVESTRI *et al.,* 2012). MADDISON (2007) describes this method: 'Open-ended questions were used to ask farmers whether they had noticed long-term changes in temperature and precipitation, and about the adaptations they had made as a response to whatever changes they had noticed.' Other authors used a similar method but replaced the perception of changes by the perception of risks (HISALI *et al.,* 2001; WILK *et al.,* 2013; TAMBO and ABDOULAYE, 2012).

This approach—dominant in the literature on climatic changes—has several limits. First of all, although perception of stress plays a role in the decision process, it is not sufficient for triggering an adaptive reaction (GROTHMAN and PATT, 2005). Furthermore, the collection of perceptions may be affected by bias (MADDISON, 2007; GBETIBOUO, 2009). Faced with a researcher, the persons surveyed may use a positive attitude with regard to the questions asked (by frequently giving affirmative replies) and the recording of perception of changes often displays little variance in the responses (see Chapter 4 of this book). Furthermore, an adaptation may reduce the risks linked with climatic variability/changes without having been knowingly made with this in mind (FAUROUX, 1989). The case of improved varieties is a good example as this generally has numerous advantages including tolerance to drought, pest resistance, better grain quality and larger yields. Finally, an adaptation to a climatic stress can be the result of a collective phenomenon not stopped by the filter of individual perceptions. This idea that certain social phenomena escape the awareness of individuals is the origin of sociology (DURKHEIM, 1897). Thus the overall dynamics of adaptation of a socio-ecological system can cause numerous mimetic reactions and the adaptation can potentially occur in this collective framework.

A comprehensive approach placing changes in practices at the heart of the procedure seems to be a much more relevant model of analysis for the study of strategies of adaptation to climatic changes. This is the approach that we present here, describing the changes made by farmers. Thus an adaptation measure should meet the following conditions in order to strengthen resilience to climatic changes and be sustainable: 1) integrate both social and ecological systems, 2) grasp the contextual nature of adaptation phenomena (the spatial dimension), and 3) take into account the multiple stresses (of climatic and non-climatic origin) in which these changes are set and that form a vulnerability factor.

In this chapter, adaptation is seen from the angles of change, decision-making and social dynamics. It is a change in farming practices implemented by farmers and set in a broader context. It is the taking of decisions and also social dynamics. A case study conducted in Djougou (Benin) shows what changes farmers have made to their practices and what meaning they ascribe to these changes. Based on combined qualitative and quantitative methodology, our analysis model uses several spatial scales. Five recent changes made by farmers are then described. These changes have the common feature of being inexpensive, driven by a search for rapid returns and involve only minor modifications to farming systems. The reasons put forward to explain these changes are related to commercial opportunities, prospects of increased yields or of a reduction of risks during the lean season.

Method

The research work is based on qualitative and quantitative methodology. First, a qualitative survey was applied in several villages (focus groups) and resource persons (interviews). The main aim was to identify changes or the introduction of new practices to provide guidelines for the questionnaire. Second, a quantitative survey of 1,211 farmers (1,102 households) was conducted in the Djougou administrative district in northern Benin. The town of Djougou is a trade hub at the centre of six roads around which the population is grouped. Two transects—in the north and the south of the district—were chosen for the quantitative survey (see Chap. 4. Fig. 1a).

Taken from agronomy and ecology, the transect method has several merits in study of changes in farming practices: 1) when used exhaustively, it can be used to study the spatial dimension of phenomena, an aspect generally made difficult by the use of sampling methods. It thus makes it possible to take into account the fact that agricultural production is subjected to constraints in access to inputs (seed, fertiliser, pesticides) and the sale of crops. The distance to the urban centre of Djougou can indeed be a constraint with regard to changes in practices; 2) it makes it possible to use several scales of analysis: the two transects form a socio-ecological system, that is to say a coherent system of social and ecological resources that interact at different space, time and organisational scales (Berkes, 2003). The geographic boundaries and system of governance of the villages form sub-systems constrained by the socio-ecological system. Thus the infrastructure of the socio-ecological system sets conditions for agricultural production (inputs, sales) and for access or privation in health and education for the households in each subsystem.

The transects were chosen to give zones with different infrastructure assets (roads, health centres and schools). The study zones total 155 sq. km and lie between latitudes N 10°02’30 - 09°27’14 and longitudes E 01°53’05 - 01°39’07. Each household was questioned in both transects. A household is defined as a set of persons, related or not, who recognise the authority of a person referred to as the ‘head of the household’ and who live under the same roof. The ‘household’ questionnaire included different modules related to the composition of the household, access to land, expenditure and the living conditions of the household. The 'farmer' questionnaire was centred on the profile of the farm operator, his perception of climatic changes and his farming activity.

Context

The study zone is at the southern boundary of the Sudan-Guinean zone and average precipitation is 1.100 mm per year (MAHÉ et *al*., 2012). Households live from rainfed farming on small areas. With a historical role of trade hub 'where practically all the caravans from east to west pass' (FONSSAGRIVES, 1900), the Djougou district thus has substantial agricultural development potential that remains non-exploited.

Farming is practiced in a context of poverty. An aggregate consumer index of expenditure shows that 54% of the households live below the extreme poverty threshold of $1.25 per day. Monetary poverty is accompanied by privation in education and health. No member of one household in two has completed five years of school attendance. As regards health, access to a potable water supply varies considerably from one sub-system to the next and malaria is endemic. Difficulties of access to care in case of malaria results in high infant mortality: nearly two-thirds of households have experienced the death of a child.

At sub-system level, local governance is handled by State representatives (counsellors and delegates) and holders of customary power (King). The latter is responsible for land tenure and decides on the attribution of land in the village. The *Centre régional de promotion de l'agriculture* (CeRPA), a decentralised Ministry of Agriculture institution, aims at ensuring the development of agriculture at the local level. Officers provide training and give advice on certain crops identified as being important. The CeRPA also handles the distribution of inputs and certain certified seed (maize, cotton, soya and rice).

The socio-ecological system of our study zone consists of 18 sub-systems of different sizes (Tab. 1). The northern transect is much more heterogeneous in terms of ethnic origin. In particular, it includes zones recently settled by Peuls or Ditamari. All or nearly all households live on rainfed farming using mainly family labour. Most households are polygamous and large. The households surveyed possessed an average land area of close to 10 hectares. There are differences between sub-systems related to soil quality (stony soil), the availability of land and the time elapsed since installation. In a general manner, land is not a limiting factor and 79% of households practice fallows, which is positive in terms of the maintenance of soil fertility. Small areas are devoted to each crop (average 0.8 ha). Two main types of crop can be considered: 1) crops for on-farm consumption: yam, cassava, maize, sorghum and millet, part of which can be sold but that are fundamental for food security; 2) commercial crops: groundnut, cotton, soya, cowpea, rice and sesame. Use of inputs is small as 82% of the crops are grown with no added substances. Inputs are used for cotton, a crop subsidised by the State, which supplies them (92% of crops), maize (41%) and lowland rice (24%).

Table 1.
Characteristics of the households and farming activity of the different sub-systems forming the two transects

	Population	Average size of households	Main ethnic groups	Land owned (ha)	Land cultivated (ha)
Northern transect					
Kpéré road - End of transect	52	9.3	Peuls	5.0	3.4
Kpéré (+ Barri road)	51	9.1	Peuls, Bariba	9.1	7.7
Kpébouco	86	8.8	Yoa, Lokpa, Ditamari and others	13.7	5.4
Aféou Nor	41	8.2	Yoa, Lokpa, Peuls	12.7	6.2
Route Tébou - Aféou Nor	32	7.6	Ditamari, Peuls, Yoa	12.3	6.4
Tébou	80	9.4	Bariba, Yoa, Peuls	14.9	6.6
Foumdea	125	8.1	Lokpa	8.3	5.0
Kolokondé	138	7.9	Peuls, Yoa, Lokpa ; Ditamari	6.0	3.7
Southern transect					
Route Kpayerou	28	9.3	Yoa	16.5	5.5
Wassa	18	7.8	Yoa	5.4	2.9
Route Djeou	49	8.0	Yoa	11.1	2.8
Faka-Faka	25	8.4	Yoa	8.1	3.3
Goumbakou (+ Kpahouya road)	113	8.1	Yoa	8.4	3.2
N'Kontaga + Tchognari	47	8.0	Yoa, Peuls, Lokpa, others	7.5	3.3
Kakindoni (+ Kokohou road)	43	7.9	Yoa, Lokpa	9.6	3.8
Koutouga road	12	8.5	Yoa, Peuls	14.0	6.4
Pélébina	130	7.8	Yoa, Peuls, Lokpa, others	8.0	6.7
Gbessou	32	9.1	Peuls, Yoa, Lokpa	5.5	2.6

Changes in farming practices

The identification of changes was performed in two stages. The changes identified by qualitative methods using interviews and focus groups then received quantitative attention. The proportion of farms that have adopted a practice varies considerably from one sub-system to the other, as is shown in Figure 1.

The most common changes made by farmers during the last ten years are discussed here: 1) tree planting; 2) changing sowing dates; 3) using new crop combinations; 4) growing new crops, especially soya; 5) growing new varieties. Care is taken to describe the context of each change and the meaning that the stakeholders ascribe to the practice.

Tree planting

Planting trees is the most widespread change in practice among the farmers in the study zone: 62% of them had planted a tree during the 10 years preceding the survey.

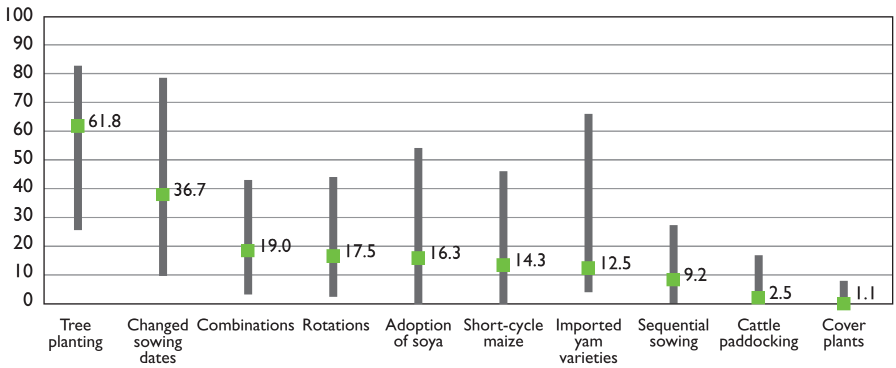

Figure 1.
Changes introduced by the farmers in the study zone.
The graph shows the average proportion of farmers who have changed their practices and shows the minimums and maximums in the sub-systems that form the study zone.
For example, while 62% of farmers planted at least one tree, the figure was only 26% in Kpéré and 83% in Kpébouco and Goumbakou.

As they absorb CO_2, trees are considered as a means for reducing the quantity of greenhouses gases in the atmosphere. In the socio-ecological system, trees slow strong winds, reduce evaporation and provide organic matter for the soil.

Table 2 shows the extent of tree planting in the various sub-systems. Three sub-systems adopted the practice strongly, planting the equivalent of 10 trees per farmer during the last decade. These sub-systems (Wassa, Faka-Faka and Koutouga) are small and a vast ecological system is available. In contrast, less planting was performed in the zones in which population density is higher (Kolokondé, Foumbéa, Pélébina) and in the recently settled zones (Kpéré road, Tébou road-Aféou Nor). The last result is somewhat contra-intuitive, given the availability of land on the pioneer fronts, and suggests a planting difficulty in a context of newly acquired and still uncertain land tenure. Planting a tree shows that the land is being appropriated and this cannot be done without the approval of the customary authorities.

Most of the trees planted (69%) are cashew). It is mentioned in the interviews that sales of cashew have improved in the last ten years, with the nuts going to local markets. Some people interviewed also mention that training was provided by the CeRPA. Then come teak and eucalyptus (17%). Finally, some farmers planted fruit trees (13%): citrus, mango and papaya. The types of tree planted differ according to the aims of the plantation, the time horizon of the returns expected and the mode of access to plants.

The reasons stated by farmers vary according to the trees. Sales form a clear objective in the case of cashew, citrus and oil palm. Eucalyptus, teak and softwood are planed for construction timber or for the sale of timber for this purpose. The time horizon of the expected return from the plantation is an important component in decision

Table 2.
Description of tree planting in the two transects during the preceding ten years.

	% of farmers who planted a tree	Total trees planted	Number of trees par head of population
Northern transect			
Kpéré road - End of transect	25.0	28	0.5
Kpéré (+ Barri road)	68.6	130	1.8
Kpébouco	81.4	167	1.4
Aféou Nor	75.6	256	5.7
Route Tébou - Aféou Nor	34.4	88	2.4
Tébou	73.8	239	2.4
Foumdea	72.8	86	0.6
Kolokondé	45.7	74	0.5
Southern transect			
Kpayerou road	57.1	116	3.5
Wassa	50.0	241	12.7
Route Djeou	67.4	113	2.4
Faka-Faka	76.0	295	11.3
Goumbakou (+ Kpahouya road)	81.4	171	1.6
N'Kontaga + Tchognari	55.3	147	2.9
Kakindoni (+ Kokohou road)	72.1	153	3.2
Koutouga road	58.3	126	9.7
Pélébina	56.2	185	1.4
Gbessou	62.5	106	3.1
Total	61.8	2 721	2.2

making by farmers. Cashew gives fruits after only a few years. Teak can be felled for use after five years. In a context of multiple stresses, the long-term prospects seem uncertain and returns from plantations should be seen in the short term by farmers. This was highlighted forcefully by several focus groups (FG):

> 'It takes 3-4 years before a return from sales for cashew. With teak, if you are unlucky you'll die before profiting from it' (FG, Kpébouco).

Finding planting material is not difficult for the trees most commonly planted (cashew and teak). Cashews are a gift or collected in the country. Wild teak saplings are replanted on the farmer's land. Minority trees require access to a nursery. This is the case in Kolokondé where a recently opened nursery has eucalyptus and fruit tree saplings at CFAF100 each.

Changes in sowing dates

The date on which crops are sown is of crucial importance. After tillage, sowing marks the start of agricultural work and is generally performed by women. The choice of planting date is linked with the beginning of the rainy season, the cycle of the varieties chosen and the farming system. Highlighted in the literature on adaptation (Bryan *et al.*, 2009; Fosu-Mensah *et al.*, 2012), changing plantation dates is often presented as an adaptation to climatic changes. In a general manner, cycles that are as long as possible are sought in traditional farming as this means larger yields (Rosenzweig and Tubiello, 2007). Adjusting sowing enables farmers to set the cycle (its length) in relation to the 'average' (in the statistical sense) progress of the rainy season.

Although choosing a sowing date can be an opportunity, it is also a risk. The focus groups set up among farmers resulted in identifying two different rainfall situations that the farmers said were dangerous: on the one hand, seasons with (too) abundant rainfall in frequency (distribution) or volume (and intensity) that causes degradation, loss of fertiliser and flooding. Crops on bottomland are particularly vulnerable. Abundant rainfall can also prevent maize from flowering or drying, which must be carried out under conditions of low relative humidity. Then there are drought periods. Good rainfall distribution is essential in particular for maize and soya: a pause in rainfall can seriously compromise these crops (Foyet-Rabot and Wybrecht, 2006).

Maize sowing dates had been adjusted by 37% of farmers during the three years preceding the survey. This means that they sowed on a different date at least once in the three previous years. Maize sowing dates in 2012, 2011 and 2010 are shown in Figure 2. It can be seen that few farmers risk sowing at the beginning of the rainy season, that is to say before May (7% of farmers). Farmers consider that June is the most propitious period as this is when slightly less than half of sowing is carried out. It is not possible to identify a clear trend in changes of sowing date from one year to another during the three years in question.

Although changing sowing dates is often considered to be an adaptation to climatic changes, it seems to be inadequate as an indicator. Indeed, constraints such as illness or unavailability of labour (structural for the farms or occasional, caused by illness

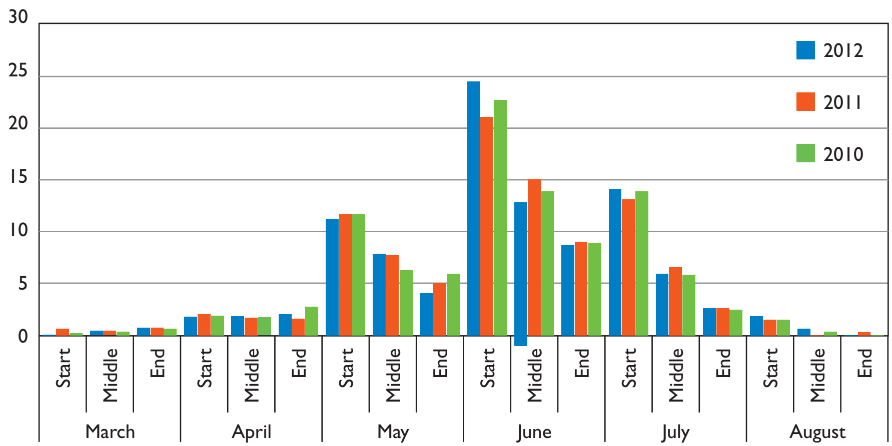

Figure 2.
Maize sowing dates in 2012, 2011 and 2010.

for example), no access to loans and/or inputs in time and/or quite simply because the ranking of their priorities for several crops can result in farmers changing their sowing dates without this being a response to the onset of the rains. Thus plantation dates here seem to be determined not according to the start of the rains but according to a risk minimisation strategy. Sowing is carried out when the rains are firmly present (June) and when farmers consider that the risk of stretch of drought is small (FG, Kpébouco).

Introduction of new crop associations

Among all the crops grown by farmers, only a quarter are accompanied by a companion crop. Crop association—defined as growing several species in a field with the cycle overlapping—generally results in competition between crops (for water, root deployment and light). However, associating certain species can generate complementarity between cycles and species (FOYET-RABOT and WYBRECHT, 2006).

The introduction of new crop associations concerns nearly one farmer in five. Sorghum is the companion crop in most cases. It is associated with maize, groundnut and yam. Sorghum has an important feature for crop association: it has a long cycle and can regulate its physiology. The yield of sorghum associated with maize is close to that of single cropping. The other associations involve maize, generally combined with yam, and millet combined with yam or groundnut.

Most of the new associations introduced in the last ten years involve maize/sorghum and yam/maize. Thus the introduction of new associations consists above all of the progression of an association already used by a fair number of farmers (maize/sorghum). Associations with legumes (maize/cowpea), that regenerate land, form a very small minority. Recommended by CeRPA agronomists, the maize/soya association is practically non-existent.

These results did not reveal a newly introduced association that would form a response to a change in climatic parameters. Crop association in Djougou is a farming practice with substantial prospects for improvement. A response to rising temperatures resulting from climatic changes and that will generate stress in numerous species could be envisaged in the form of appropriate crop associations.

The introduction of new crops: soya

At the scale of the two transects, nearly one farmer in two (47%) has planted a new crop in the past ten years (Fig. 3). The range of these crops provides a glimpse of the strong dynamics of the farming systems.

The crops most frequently introduced during the last ten years are soya (16%), maize (12%) and lowland rice (11%). Soya displays the strongest growth with obvious spatial dynamics and the crop is examined closely in this chapter. A major innovation in certain sub-systems, soya also has various possibilities (consumption, soybean cheese processing or sale,).

The introduction of soya in certain sub-systems concerned one farmer in two. This is the case in Kpéré, where soya was introduced 20 years ago and has spread widely.

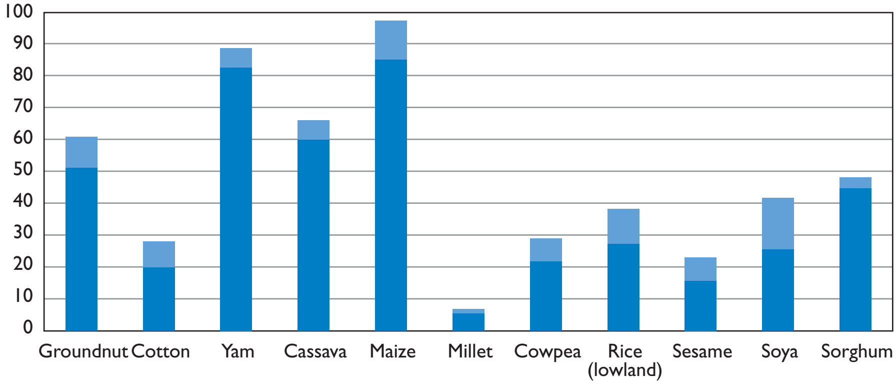

Figure 3.
The proportion of farmers who planted the crop listed during the 2012 farming season. The crops introduced during the past 10 years are shown in pale blue.

More 3-month soya (71%) is grown than 4-month soya and the local market is the main source of seed. Soya growing is involved in very different strategies.

First, soya forms a commercial opportunity and can generate immediate returns. It is sold at a higher price than maize (CFAF300 to CFAF700 per kg in comparison with CFAF200 to CFAF500 per kg for maize according to the time of year) and keeps well. Soya can be eaten and sold throughout the year to face difficulties. Women also use soya to make soy cheese. Although only 10% of the farmers in our study zone are women, they form 28% of soya growers. Soya can be eaten in the household, generally accompanied by a sauce. Health centres highlight its nutritional merits, especially for children (FG, Wassa). It can also be sold, providing a source of income for women. Several projects have been run in the zone to promote the technique for processing soya to make cheese. At Wassa, three-legged stoves have been set up in the centre of the village so that the women can make and sell soy cheese. Mastery of the technique is generally via a family member who is often from another village. Soya is purchased at an average CFAF1,000 and cheese is sold at CFAF1,500.

The farmers who have not started to grow soya mention the poor quality of their soil, not mastering the technique (FG, Koutouga) or the presence of pests (FG, Wassa). The shortage of available labour is also an important factor (FG, Goumbakou and Aféou Nor), leading to suppose that those who start growing soya have labour mobilisation strategies. Indeed, for farmers who are heads of households growing soya is always a complement to the traditional food crops yam, sorghum and maize.

Introduction of new maize and yam varieties

Maize and yam form the foundation of food security for households, and farmers have succeeded in profiting from the opportunities provided by new varieties. They are short cycle varieties sold by the CeRPA in the case of maize or varieties with higher yields, generally imported from Nigeria in the case of yam.

Usually accompanied by the abandoning of the traditional varieties, the adoption of short cycle maize concerns 14% of farmers. Bred by the *Institut national des recherches agricole du Bénin* (Inrab) in collaboration with the International Institute for Tropical Agriculture (IITA), two varieties are sold at the CeRPA in Djougou. The varieties EV DT 97 STR W, called *Mougnangui* ('tough'), 90 days, and 2000 syn. EE W, called *Ku Gnaayi* ('famine fighter'), 75 days, are described as drought-tolerant (MAEP technical document, 2010). This shortened maize cycle is an improvement in comparison with the 120-day cycle of traditional maize (*Inspection générale de l'agriculture coloniale*, 1908). These are composite maize varieties whose seed can be used for 2-3 years although performances decrease with time.

Obtaining seed supplies from the CeRPA in Djougou is still a barrier for a fair number of farmers. The obstacles are geographic and economic. First, some sub-systems are far from the CeRPA, encouraging the use of seed purchased on the markets and more readily available. It was thus seen that several sub-systems—generally small and not on the main road route (Kpayérou, Koutouga, Kpéré)—have hardly switched to short cycle maize at all. Second, the short-cycle varieties available from the CeRPA are sold at higher prices on the markets. In 2012, EV DT 97 STR W maize was sold at CFAF500 per kg while a 90-day maize could be purchased on the market for the equivalent of CFAF300 per kg. However, numerous farmers mention that they are certain to obtain a 3-month maize variety from the CeRPA, which is not the case when seed is purchased on the market:

> 'On the market, people mix the varieties and you end up with any old thing. You can never be sure that it really is 3-month maize' (FG, Faka-Faka).

As a result, one in two farmers who sowed short-cycle maize in 2012 obtained it from the CeRPA. Use of a short-cycle variety has obvious links with climatic variability: the longer a variety takes to ripen, the more it is exposed to the risk of the plant failing to reach maturity.

In contrast with maize, a plant imported to Africa from America, yam growing has a long history in the region (*Inspection générale de l'agriculture coloniale*, 1908; Chevalier, 1912). Two types of yam are grown: *Dioscorea cayenensis*, large 12-month yams, and *Dioscorea rotundata*, small 8-month yams. Large yams are generally grown in sandy soil and the small ones in hard soil. Yam requires fertile soil and organic matter, especially for the early varieties (Foyet-Rabot and Wybrecht, 2006).

In addition to the traditional varieties Assouna and Noudoss, varieties from other regions have developed and are sometimes commonly called 'Bariba' or 'Yoruba' yam. The main varieties imported to the zone and grown by farmers are Yanouha, Morkonnoudje, Coutonouma, Kpataga, Idolona, Palacana and Wotanam. These are names in vernacular languages and it has not been possible to link them to their scientific names. The great majority consists of early varieties. They also stand out for their multiplication, considered to be easier.

In the last ten years, 12.5% of farmers started growing a new type of yam. However, this figure hides considerable differences from one sub-system to another. Some sub-systems are particularly innovative as this practice sometimes concerns one in two of the farmers (Wassa) and two in three (Faka-Faka). But the trend is very weak in some zones such as Tébou, Kpébouco and the Koutouga road (less than 5% of farmers). Migration phenomena seem to account for the origin and dispersion of the varieties in the study zone. The introduction of a variety in a sub-system may go back to the migration of the farmer's family members (FG, Pélébina): when they returned, they had no more planting material and brought with them yam varieties from their migration zone. This feature may also be linked with more recent migration. In Faka-Faka, the variety Yonouha has taken precedent over the others because of its better productivity and the multiplication method (a piece of yam can be used, unlike the local varieties planted from material formed after the harvesting of the first tubers). It was imported by one of the farmers in the village who had gone to do farm work in Kissi in Nigeria. The variety then spread in the village by gifts of planting material and subsequently by sale of seed. Now, a few years later, it is grown by two-thirds of the farmers of Faka-Faka.

Table 3 shows the reasons for the adoption of short maize varieties and imported yams. It is seen in both cases that the climatic reasons (drought/irregular rainfall for short cycle maize) or environmental features (poor soils for yam) are in the minority. For maize, the varietal characteristics of the plant (short cycle and better yield) are

Table 3.
Reasons put forward to justify the introduction of a new maize or yam variety during the last 10 years. Several possible replies.

	Maize	Yam
Availability of seed/planting material		
Varieties with free/inexpensive seed/planting material	0.8	6.3
Varieties with easily obtained seed/planting material	7.3	7.5
Variety recommended by the CeRPA	1.1	0.0
Variety recommended by friend/family	3.5	7.7
Varietal characteristics		
Better yield	18.6	24.9
Several harvest each year	1.4	4.0
Can be harvested earlier	30.9	9.1
Less fertiliser required	4.3	0.7
Better resistance to drought/irregular rainfall	3.0	1.0
Better resistance to flooding	0.1	0.0
Better resistance to weeds	0.1	0.2
Contains more meal	4.6	/
Better suited to poor soil	0.0	0.9
Better taste	6.9	12.2
Harvest and sales		
Easier to sell	4.7	6.8
Keeps better	0.5	0.3
Ready during the lean period	5.8	8.7
Other	6.1	9.8
Total	*100*	*100*

the main reasons put forward. Farmers stress the fact that this variety can be harvested during the lean period when resources are generally lacking. In the case of short cycle maize, although climate is an adaptation factor it is neither the only one nor the triggering feature. For yam, better yield is the main reason mentioned by farmers (25%). This is followed by taste qualities and the fact that it cannot be harvested earlier, coinciding with the lean period. Emphasis on taste qualities and culinary preparation and fact of relying more on recommendations form the distinction between yam and maize.

In both cases these changes in practices are linked with household food security. Better yields and, above all, an earlier crop are the main reasons that encourage farmers to use new varieties. This being so and considering the uncertainties and risks in farming, farmers first examine the time scale of the farming cycle and the lean period to justify these changes. The time scale of rainfall seems little or not at all involved in their decision-making. At most we can see perhaps a convergence of interests between the decrease in the rainfall risk and the fact of being able to harvest earlier during a period that is usually difficult.

Conclusion

Farmers are innovating and modifying their farming practices in a context of poverty that is characteristic of West African rural communities. The common features of the changes described in this chapter are their low cost, a relatively small degree of adjustment of systems and the search for returns within a limited time horizon. In their changes, farmers favour short-term food security above all. These strategies may seem to be forms of response to poverty and its consequences and provide information about the past and present capacity of farmers to adapt to climatic changes.

Examined in a comprehensive manner, the reasons for changes in practices has allowed us to show that a change can reduce the risks associated with climatic variability/changes without this change being implemented knowingly with this in mind. On the one hand, the meaning stakeholders award to their adaptive practices leaves little room for climatic or environmental reasons. Farmers mention more the commercial opportunities available, the prospect of increasing yields or reducing risks during the lean period. Thus the introduction of new drought-resistant maize varieties that increase resilience with regard to climatic changes is little mentioned as such by farmers. On the other hand, as is the case of tree planting, it is seen that certain changes can increase resilience to future climatic changes by contributing ecological value-added (contributing organic matter and absorbing CO_2). Although this is not at all the objective of farmers, we consider that from the angle of sustainable development it is important to consider the consequences of adaptations for the socio-ecological system.

Our approach has also shown that adaptation seems to be intrinsically linked to its context, guided by social norms and interactions that, beyond individual decisions, express the dynamics of the sub-systems. Through using different space scales (the socio-ecological system, subsystems and households), this work shows that each sub-system outlines a different figure of the adaptation. At the socio-ecological system level, spatial variables play an important role, conditioning farmers' constraints and opportunities. At sub-system level, social phenomena potentially escaping perception by farmers are probably in progress. At household and farmer level, different objectives and priorities can explain the decision-making that leads to the adaptation. It therefore seems entirely possible that an adaptation strategy can result from a collective phenomenon, going through the filter of individual perceptions.

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Chapter 18

The return of Sanio millet in the Sine

Rational adaptation to climate evolution

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Bassirou SINE

Introduction

Sanio millet[1] has reappeared in villages in the Sine, between Bambey, Diourbel and Fatick, since the mid-2000s. However, this long cycle millet had disappeared from farms in the northern half of Senegal in the 1970s because of the sudden decrease in rainfall. It was still present further south in the wetter regions of Saloum and beyond as far as the Casamance. As rainfall depths increased from the mid-1990s everywhere in Senegal (SALACK *et al.*, 2011), we put forward the hypothesis that this return could form a robust agronomic 'marker' of recent pluviometric evolution in central-western Senegal and show the ability of farmers to adapt rapidly and independently—i.e. without the support of agronomic engineering[2]—to changes in their environment.

However, although the climatic opportunity provided by the return of rainfall seems to be a necessary condition for the production of Sanio, it may not be enough to explain why Sanio is not chosen by all farmers, as it was in the past. Since the climate change theme has become an ordinary paradigm of science and public action, it has become commonplace to recognise that agriculture in Africa lacks financial and technological resources for adapting to climatic and environmental events (ADGER, 2006a and 2006b). But individual or collective adaptation is not new for African

1. 'Sanio' is the Wolof name for this millet variety. The Serer in the Sine call it 'Matye' (pronounced 'match').

2. After the dry decades, research has been focused mainly on promoting short cycle varieties with small demand for water.

farmers, who put up every day with precariousness (of resources and living conditions) resulting from variations and extreme climatic events. It is above all an inherent need in any strategy for the survival of the most vulnerable families. Thus, in the same way that the climate is probably not a sufficient condition for adaptation, poverty is not an absolute limit either. Adaptation (or the option of adaptation) responds to a complex set of constraints, opportunities and choices driven by farmers' pathways and capacity. The agricultural and cultural memory of the stakeholders and the system, famers' resources (land, labour and funds), the farming system used and professional influences can explain among other factors that considerable differences are observed in agricultural adaptation practices in the same climatic context and in a generally poor farming community.

Within the framework of the ESCAPE project (2011-2015), we examined the reappearance of Sanio millet in the Serer agricultural region between Bambey, Diourbel and Fatick in order to gauge its scale and to understand the different determinants, whether these were biophysical, economic or socio-cultural. First of all, we wanted to verify the role of the increase of rainfall in this process and evaluate the impact of climatic risks on the production of this crop. A sociological and agronomic survey was conducted on a sample of 1000 farms and completed by discussion with farmers and field observations. This gave an explanatory model of the return of Sanio on farms and an assessment of the areas used for the crop. Finally, we undertook a description of the dynamics of the sowing of Sanio using a spatial and historical analysis. The first local history of Sanio was reconstructed in order to examine the capacities and limits of adaptation to climate change of small family farms in this region of Senegal.

An agropastoral region with climatic and demographic constraints

Our study zone is in the Senegalese groundnut zone, south of the former Baol kingdom, and covers the north of the former Serer kingdom in the Sine and the administrative regions of Fatick (mainly), Diourbel, Thiès and Kaolack (BECKER and MBODJ, 1999; BECKER, 2014). The Sine area, population and society have been described at length since the independence of Senegal (PELISSIER, 1966; CANTRELLE, 1966; LERICOLLAIS, 1972) thanks in particular to a system of ecological, social and sanitary observation of 30 villages in the Niakhar administrative unit (DELAUNAY *et al.*, 2013) for over 50 years.

The region has a semi-arid Sudano-Sahelian climate. Temperatures are high (average 28.1°C in Bambey in 1980-2013) and rainfall is low (512, 474 and 546 mm respectively at Bambey, Niakhar and Fatick in 1980-2013), with precipitations mainly between mid-June and the end of September, with strong inter-annual variability in

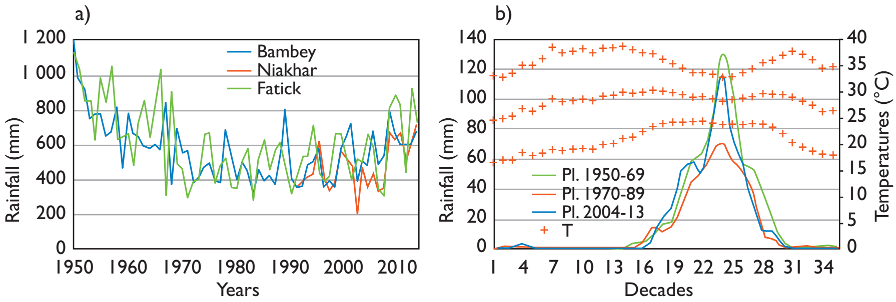

Figure 1.

Figure 1. (a) Evolutions of annual rainfall since 1950;
(b) average decadal pluviometry for the periods 1950-1969, 1970-1989 and 2004-2013 and maximum, minimum and mean temperatures at Bambey for the period 1990-2013.

quantity and distribution (Fig. 1a and 1b). The short rainy season, referred to as 'winter', means that only one crop cycle is possible each year. As everywhere else in the Sahel, rainfall decreased strongly at the beginning of the 1970s, falling from 719 mm in Bambey (780 mm in Fatick) for 1950-1969 to 478 mm (604 mm) during the next 20 years. The dry phase lasted for nearly three decades before a recovery of cumulated rainfall in the mid-1990, and in particular an improvement from August to mid-September (Salack *et al.*, 2011).

The agropastoral system has kept its dominant original features for more than 50 years. The positions of villages and the first land clearance were preferably on flat areas of soil called *dior*. These are predominantly sandy soils with a permeable upper horizon and easy to plough and loosen. However, moisture retention and fertility are mediocre, generally leaving peripheral low-lying zones of sandy clayey '*dek*' soil (5 to 10% clay in comparison with 2 to 5% in '*dior*' soil). This soil is less present, more fertile and has better moisture retention capacity but is less permeable and hardens rapidly after rain. This land is used mainly for millet *(Pennisetum glaucum)*[3] and groundnut *(Arachis hypogaea)*, but crops also include sorghum *(Sorghum bicolor)*, cowpea *(Vigna unguiculata* subsp. *unguiculata)* and roselle (*Hibiscus sabdariffa*). Millet is a basic food crop while cash income is drawn mainly from groundnut, which also contributes to food supplies (grains, oil and stalks for livestock). In recent years income has been more frequently complemented by sheep and even cattle fattening and by other crops such as watermelon (*Citrullus lanatus*).

There are two types of millet—Souna and Sanio. They have been bred for several centuries to adapt to climatic uncertainties, soils and farmers' requirements (grain and straw). Souna millet[4] has a short cycle lasting about 3 months and is fairly constant as it has low photoperiod sensitivity. The cycle of Sanio millet is about a month to a month and a half longer and varies according to the sowing date as it is much more sensitive to the photoperiod. This character is adaptive to the date of the start of the rainy season (Vaksmann *et al.*, 1996; Kouressy *et al.*, 2008), enabling the plant to

3. Pearl millet has several names, including '*mil pénicillaire*', '*mil à chandelles*', '*petit mil*' and '*mil perlé*'.
4. ' Souna' is a Wolof term. The Serer word is 'Pod'.

Figure 2.
Figure 2. Photos of Serer land and agricultural practices.
Top to bottom and left to right: the country during the dry season; paddocking area; sowing with an animal draught seeder (groundnut here); emergence of millet; millet at about 1 month; Faidherbia albida *acacia and its fertilising effect; growing millet; Souna millet shortly before harvesting; groundnut shortly before harvesting; Sanio millet shortly before harvesting; Amadou Diouf, a Serer farmer in Nguayokhèm who has never stopped growing Sanio, holding a Sanio plant here; using an animal draught hoe to lift groundnut during the harvest; Souna millet stalks and the granaries in which they will be stored; storage of millet straw in stacks and cowpea stalks in baobabs.*

adjust its cycle length to that of wintering. Depending on rainfall, if they germinate early—that is to say in the first 10 days of June—the cycles of Sanio and Souna are some 135-140 and 95 days respectively, whereas if they germinate late at the end of July or the beginning of August their cycles last approximately 110 and 85 days. Sanio is taller (3-3.5 m in comparison with 2-2.5 m) and has more stems and straw than Souna but nevertheless the same quantity of grain, or perhaps a little less, with crop potential peaking at 3 tonnes per hectare under the best conditions (DANCETTE, 1983 a and b; SIÉNÉ LAOPÉ *et al.*, 2010). In relation to this figure, it is useful to remember that farmers' millet yields in this region vary from 500 to 700 kg/ha (average figures for the last two decades) because of numerous constraints (low fertility, small fertiliser application, biotic attacks) in addition to rainfall deficits (KOUAKOU *et al.*, 2013).

Finally, Sanio differs from Souna in its aristate heads (Fig 3a): the term indicates the presence of long rigid awns (5 to 6 cm), also called beards, that protect millet spikes very effectively from attack by birds. Souna millet spikes do not have awns (Fig. 3b). The character is very useful at the end of wintering when Sanio millet is alone in the landscape and is thus a clearly visible target for millet-eating birds (*Quelea quelea*). This protection means that farmers can take their time and award priority to other agricultural work (groundnut harvest and postharvest operations) before harvesting Sanio. It should be added that Sanio grains are distinctly larger than those of Souna[5]. In addition to their exceptional adaptation to drought, Souna and Sanio millet are adapted to light, poor *dior* soils, even if Sanio also grows in slightly more hydromorphic *dek-dior* soils. Grain and straw production are completed by those of groundnut, grown in the same soils, and of sorghum that does well in *dek* soils. This agro-diversity is also a good feature for the staggering of farmwork.

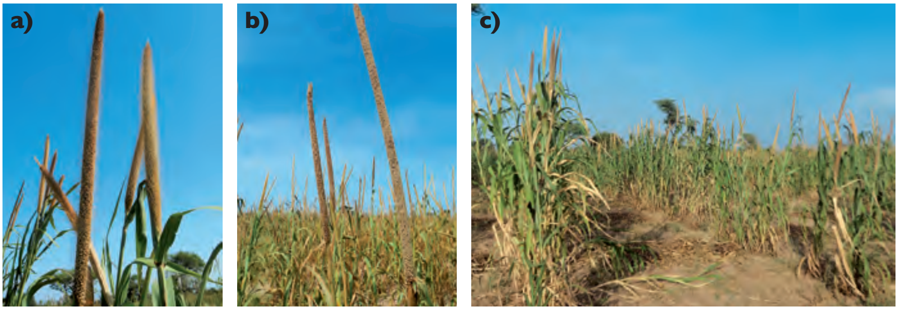

Figure 3.
(a) spikes of Sanio; (b) spikes of Souna; (c) rows of Sanio (after the harvesting of Souna).

Livestock are associated with crops in an agropastoral system that is exceptional in West Africa. Numerous herds and flocks belonging to sedentary farmers roam fields abandoned to grazing for varying periods during the dry season. Most then leave in transhumance in the rainy season and some are kept on local land in the rare fields where enclosed annual fallows are still used (FAYE *et al.*, 1999). Livestock obviously benefit from crop residues too. The combination of crop and livestock farming maintains soil fertility without the need for long fallows. In fact, the maintenance of

5. This varies according to filling. Maximum weights of 1000 grains are 8 to 9 grams for Souna and 10 to 12 grams for Sanio. However, Sanio grains are often smaller than Souna grains because of the shortage of water at the end of the season.

fertility results from several complementary factors: 1) a grain crop with small requirements—millet, 2) the use of flock and herd manure either directly in paddocking or by the transport of manure and litter, 3) the use of domestic organic wastes, 4) respect of a grain-legume rotation generally combining millet and groundnut, 5) fallows and 6) the maintenance of afforestation with *Faidherbia albida* acacia whose nitrogen-rich leaves are cut for livestock or fall to the ground to create 'patches of fertility' (Fig. 2).

These complementary practices have contributed to the structuring of local land areas, with first a circle of fields ('*champs de case*') around dwellings. These are the most fertile as they benefit from domestic wastes and paddocking—especially of small ruminants—and possible manure application. Outside the circle are found other 'bush fields' with other fertility management methods in proportions that have varied in time and differ a little between villages. In addition, *champs de case* were traditionally managed with continuous monoculture of Souna millet while Sanio millet, together with groundnut and fallows, accounted for the majority of the arable bush fields and was a dominant feature of the landscape (LERICOLLAIS, 1972). This distribution gave the best management of food security. The omnipresence of tree and the fine mosaic of fields are the result of long, ancient fashioning of the landscape by farmers.

These practices and the use of animal draught seeders and hoes allowed annual use of almost all the agricultural land. This land thus ensured the maintenance of a growing population in spite of the (imposed) abandoning on one-year enclosed fallows from the 1970s onwards (LERICOLLAIS, 1972; GARIN *et al.*, 1999). Sine has thus long been described as one of the most densely populated parts of Senegal. In 1966, CANTRELLE (1969) estimated the population density in the Niakhar district to be 85 per km² (in comparison with 15 per km² for Senegal as a whole). In 2013, the population density in the 30 villages observed in the Niakhar district reached an average of 226 per km², with the density in three village exceeding 400 per km². However, seasonal migration has lessened the population pressure slightly since the beginning of the 21st century as, depending on the month, 6% to 11% of the population is temporarily absent from the villages (see Chapter 14).

In 1934, the colonial authorities launched a programme aimed at favouring the settlement of 'new lands' around Kaffrine by Serer from the Sine and the Saloum—reputed to be good farmers—while reducing pressure on the Sine areas that was already considered to be saturated. This idea was taken up and amplified after independence in the third 4-year plan (1969-1973). Thus from 1972 to 1980, the Senegalese authorities organised the movement of several thousand Serer families although they were deeply attached to their land even though it was densely occupied. These managed and then spontaneous population flows were not as intense as expected (5.3% of the families counted in 1976 in the Niakhar district had left to colonise the pioneer fronts of the 'new lands' of eastern Senegal between 1972 and 1987) but they contributed to release land and gain about 5 years of population growth in this district (GARENNE and LOMBARD, 1988). It is estimated that in the 2000s definitive departures totalled an average of 700 per year in the Niakhar observation zone (that has a population of more than 40,000). This emigration was mainly for nuptial and family reasons (see Chap. 14). Finally, the continuous and accelerated population increase has resulted in divisions of property when land is passed, with the sub-division of fields and necessitating technical innovation and farming potential. In the land at Sob (a village in the Niakhar observation zone), field size decreased from 1.23 ha (LERICOLLAIS, 1972) to 0.84 ha (the authors' calculation) between 1965 and 2012 (47 years), that is to say a decrease of a third.

In addition to the rapid growth of the population, climate is the most important macro-factor with regard to the evolution of Sahelian agrosystems. The climate shock of the 1970s thus strongly modified landscape and disturbed local areas. Shortage of rainfall resulted in a considerable decrease in the number of trees: in the village of Sob, the number of Faidherbia *albida*, a tree whose importance has been mentioned, decreased by nearly 34% from 1965 to 1985 (LERICOLLAIS, 1990). Likewise, the decrease of rainfall and the shortening of the rainy season resulted in the abandoning of Sanio millet. Lericollais observed that from 1965 to 1967 this formed three-quarters of the area sown with millet (LERICOLLAIS, 1972). After the major droughts of the 1970s, the crop disappeared almost completely from the Niakhar district.

Material and methods

Our analysis of the return of Sanio combined several methodological approaches, ranging from field observations to modelling using quantitative surveys and simulation. These aspects were completed by the gathering of statements concerning farmers' practices and motivation.

Study of the climate determinant in the return of Sanio

The role played by the climate in the return of Sanio was studied through its impacts on production by performing simulation of the growth and yields of Sanio and Souna during the period 1950-2013. This was performed using the crop development simulation model SarraH©CIRAD (BARON *et al.*, 2005; DINGKHUN *et al.*, 2003) and the official rainfall records for Bambey (14°42'38''N; 16°29'00''W), Niakhar (14°29'10''N; 16°23'48''W) and Fatick (14°20'20''N; 16°24'20''W) and climatic data for Bambey. A single soil type was considered, with average available water capacity of 90 mm/m, as in this region millet is grown in sandy *dior* and *dior-deck* soils whose available capacity ranges from 80 to 100 mm/m (AFFHOLDER, 1995). The parameters used for the simulations of the varieties Souna and Sanio were those of KOUAKOU *et al.* (2013) and differed only in cycle lengths with, in particular, respect of the photoperiod sensitivity of Sanio described above. The criterion used in the simulations for the start of sowing was cumulated rainfall of at least 15 mm during two consecutive days. This is very realistic and close to farming conditions as millet is sown dry before the rains in this region at the end of May and beginning of June and germination takes place with rainfall of some 12 to 15 mm. Other sowing criteria were simulated and in particular that of Sivakumar (1988)[6] but they did not cause any particular difference in the results.

Analysis of the social, economic and cultural factors associated with the return of Sanio

To gain information about social and farming logic and the driving forces that led Serer farmers to grow Sanio or not, our main work was a survey with a double questionnaire in 30 villages in the Niakhar district (i.e. within the framework of the IRD Niakhar Health and Demographic Surveillance System[7]), covering a random sample of 1,061 family farms (32% of the households under observation). Two questionnaires were submitted at each farm. A 'household' questionnaire was submitted to the head of the farm; this made it possible to set out the cropping system used in the 2013 rainy season. In addition, more than 45 questions concerned the growing of Sanio and Souna millet. An 'individual' questionnaire was then submitted to a farmer chosen at random among the farmers of the household who had cultivated at least one field during the three years preceding the survey. This questionnaire was focused on certain crops intended for sale, such as groundnut and watermelon, or for cattle fattening. Questions also concerned perceptions of the past and present climate and knowledge about climate change. The survey was conducted from December 2013 to March 2014.

The survey using questionnaires was completed by various focus groups and individual interviews that enabled us to better understand decision making processes and reasoning that were favourable or unfavourable with regard to the growing of Sanio. The group interviews also led to collecting information about the history of Sanio in the villages, its maintaining during the drought period and its distribution among Serer farmers and in the area. The main focus groups were held in the villages of Sob (March 2012), Ngayokhèm (November 2013 and October 2014) and Keur Ngane (November 2013).

The explanatory model of Sanio growing was developed using data from the questionnaire survey completed by information collected on a routine basis by the IRD Niakhar Health and Demographic Surveillance System. Analysis of the data was performed in two stages. The first consisted of developing a number of predictors. The number of persons old enough to participate in work in the fields (> 6 years old) and average duration of seasonal migration of adult men (15-55 years old) are two indicators developed by processing demographic data (Niakhar surveillance system). A cash poverty index was developed from household purchases of goods (food and non-food). The food poverty threshold was determined on the basis of the set of foods eaten by the household, with the size and composition of the latter taken into account.

6. Sivakumar defined a criterion for the successful sowing and establishment for millet consisting of a minimum of 30 mm rainfall during 3 consecutive days followed by no dry spell longer than 7 days during the next 30 days.

7. See Delaunay et *al.* (2013) for a description of the Niakhar Health and Demographic Surveillance System.

The non-food poverty threshold is based on the average consumption of non-food goods per adult-equivalent per day for households whose food consumption is close to the food poverty level. The total poverty line (food + non-food) is CFAF 479 in the Niakhar zone. Once this threshold had been defined, we valued the daily consumption of households to classify them on either side of the poverty line. The incidence of cash poverty was assessed at 52% in the Niakhar area.

To show that the increase in rainfall is a necessary condition but not sufficient for the growing of Sanio in the region, we assessed the effect of the characteristics of the farmer and his farm on the growing of this grain. Among individual and household variables, the model takes into account the sex of the farmer, his/her perception of the present climate, the past growing of Sanio millet by the farmer's father, the average duration of seasonal migration by the men of the household, the dominant caste of the household, the cash poverty of the household and the number of household members of working age. The farm variables considered were the labour available, the farm area owned, the borrowing of land, commercial production (watermelon and beef fattening) and the number of workers in the household with an income from a source other than farming. The model was tested using binary logistic regression with the Stata® 13.1 program (2014; Stata Corporation, College Station, Texas, USA).

The sample developed for the ESCAPE survey was designed to be representative of all the 30 villages monitored. However, the variable to be explained—growing Sanio millet—was found to be fairly rare in farming (as discussed below Sanio is grown by only 25.4% of the households surveyed) and very unevenly distributed among the 30 villages. The logistic model was subsequently found to be not robust enough (poor capacity of the mode to predict the farmers that had grown Sanio). We therefore performed an analytic correction of the sample by case-control sampling to increase the sensitivity of the prediction model. The numbers of farmers were knowingly balanced between those who had grown Sanio and those who had not. The model tested on the non-representative sample gives results that, as they are, cannot predict the use of Sanio. However, the capacity of the model to explain the choice of growing Sanio remains unchanged insofar as the coefficients associated with the explanatory variables are not changed. In fact, all the statistical inference concerning the coefficients remains valid: confidence interval, significance test and odds ratio (Rakotomalala, 2014). Finally, we cleaned the model data (analysis of residuals) by removing outliers and those that weighed on the model in an exaggerated manner (leverage points and influential points). The corrected and cleaned model was much more robust (Hosmer Lemeshow test) and its sensitivity increased from 19% before adjustment to 62% after this (Table 1).

Cartography of the present cultivation of Sanio and its spread

Sanio millet has always been grown in the south of our investigation zone, that is to say in zones that are naturally wetter. We thus wished to understand the dynamics of the reappearance and spread of Sanio in our study region, a drier area between

Bambey and Diourbel in the north, Fatick in the south, Fissel in the west and Gossas in the east. As the zone is larger (more than 1,000 km²), we defined a simple, rapid method to obtain reliable information about the presence and the date of reappearance of Sanio in this area. The work consisted of travelling along the roads and tracks in the zone and questioning farmers in each village, using a questionnaire with about a dozen questions. The geographic coordinates of the site were recorded by GPS in each case. The questions concerned 1) Sanio growing in the 2013 rainy season, 2) the year that it had reappeared in the village, 3) the advantages and disadvantages of Sanio as a crop and 4) the presence and names of farmers who had never stopped growing it. Although only a small number of questions were used, they enabled validation checking and the telephone numbers collected allowed certain verifications to be made. This 'light' geographic survey was conducted from April to August 2014. In all, we obtained information about Sanio growing at 240 locations in 2013. The double questionnaire survey conducted in the Niakhar zone also provided information about the dates of the resumption of Sanio growing in the 30 villages covered.

A crop that is possible again but still risky

The simulations performed during g the period 1950-2013 show that the decrease in rainfall meant that it was no longer possible to obtain even modest regular yields of Sanio during the 1970s and 1980s and almost the whole of the 1990s (Fig. 4a). Growing Sanio only started to be really possible again at the beginning of the 2000s. However, it has always been possible to grow Souna millet, but of course with a few very bad years. The water constraints on Sanio production decreased distinctly overall from the end of the 1990s but with poor performance in some recent years[8]. In contrast, it is observed that it has always been possible to achieve good straw production with Sanio. This biomass production is usually greater than that of Souna production (open field sowing using the same procedures) because its cycle is about a month longer and it is tall. Indeed, it is mainly the flowering and grain formation phases—that start roughly when Souna is reaching maturity—that can be subject in the zone to strong water constraints, depending on the earliness of the end of the rainy season.

These results correspond in all respects with the information provided by farmers (focus groups, interviews and surveys). Almost all explain that Sanio was no longer grown because its cycle was no longer compatible with the small rainfall that was concentrated in time—a little more than two months— in the 1970s, 1980s and 1990s

8. For example, in 2002 rainfall was historically low in the Niakhar zone with hardly more than 200 mm.

(Fig. 7b). According to the farmers again, the beginning of the 1980s seems to have been when Sanio was abandoned, doubtless as a result of a succession of poor crops during the 1970s. On the other hand, they observed that climatic conditions were favourable for Sanio again towards the mid-2000s. Thus, in the questionnaire survey of the Niakhar district, growers of Sanio stated that this millet variety reappeared in 2007 (on average) and that they had been growing it since 2009 (on average). Finally, 17% of these farmers stated that Sanio had never disappeared from the crops of their villages; two thirds (63%) of the farmers saying this live in the villages of Sass Ndiafadji, Ngayokhèm, Kalom Ndoffane and Diohine.

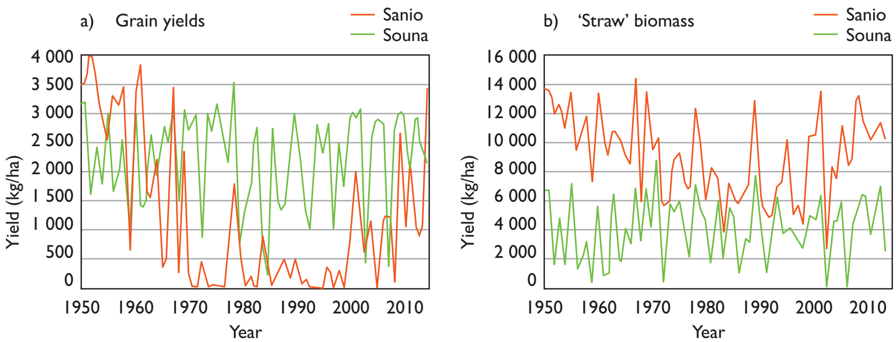

Figure 4.
Simulation of (a) grain yields and
(b) straw biomass (stems and leaves) in Sanio and Souna millet
during the period 1950-2013.

In addition to, and linked with, the climatic risk, farmers mention insect-related risks. Each of the two risks is mentioned in approximately 40% of answers to the question concerning the problems and disadvantages of growing Sanio (Fig. 5b). The farmers stress that insects damage Sanio especially in the years when rainfall ends early (the problem can also affect Souna millet but to a much lesser degree). The insects concerned are blister beetles (*Psalydolytta vestita* and *Psalydolytta fusca*) and earwigs (*Forficula senegalensis*) that suck and destroy ovules and grains. Most farmers say that losses can be considerably more than 50% of Sanio grain and some mention grain losses of 80% to 90%! Furthermore, questioned about the reason for the abandoning of Sanio, a few old farmers even mentioned 'the abundance of insects' before talking about the decrease in rainfall. Finally, in a few villages where Sanio had not yet been introduced but that are juxtaposed with villages that had started growing Sanio again, the farmers pointed out that insects tended to attack the crops of the precursors growing Sanio and even attacked Souna as well. According to these farmers, this is a strong constraint for the replanting (and distribution) of Sanio. Although we have not analysed the problem more deeply, it thus seem reasonable to consider that the pressure of these insects increased in the 1970s as one dry year followed another and the area under Sanio decreased and that this may have contributed to speeding up its disappearance.

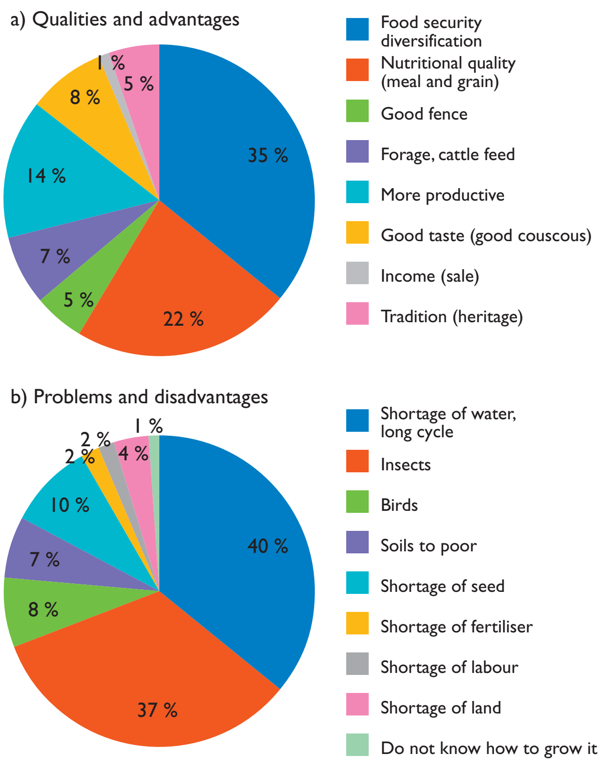

Figure 5.
Qualities, advantages and interesting features (a) and problems, constraints and disadvantages (b) of Sanio mentioned by farmers (% of times that the factor is mentioned; several factors may be mentioned) (light geographic survey, ESCAPE 2014).

A crop whose qualities are appreciated and that is easy to grow but of no monetary interest

Sanio grain and stems have many qualities that are of interest to farmers. When asked questions such as ‘Why do you grow Sanio millet?’ or ‘What are the advantages of Sanio?’ in focus groups, interviews and surveys farmers always highlight the food quality of Sanio grain (and/or meal) and the quality of residues, more precisely of stems, saying that it tastes better, makes better couscous, is easier to digest and is more filling than Souna. We were also told that it is easier to eat uncooked after soaking in water (a method used by shepherds, who add sugar) than Souna and that this is more pleasant with Sanio because the grains are larger and tastier than those of Souna. But we were also told that Sanio meal, couscous and boiled grain kept less well during the winter (they do not last through the night once cooked) than those of Souna and so it was preferable ‘to eat Sanio before the next winter’, because ‘it caused children’s diseases during wintering’. There are thus clear differences between the grain of the two types of millet that farmers know well.

Sanio stems are much appreciated—more than those of Souna—for roofing and fences ‘that last for a long time with Sanio’. They are also considered to be better as forage than those of Souna and ‘almost as good as those of sorghum’. In addition, when farmers mention cultivation risks in the form of small yields or no crop at all in certain years they insist that ‘there are always stems’. Finally, some farmers asked us whether it would be possible ‘to have millets with the cycle of Souna for grain and stems like Sanio’—a clear summary of things.

The main and almost only weakness of Sanio are the problems mentioned above, that is to say risks linked to rainfall and damage by insects (Fig. 5b). More rarely, certain farmers also mention soil fertility weaknesses and say that Sanio millet needs fertile, more clayey soil (*dek* type) to give a good yield. Finally, even if this is little mentioned directly by farmers, another weakness of Sanio is that it is hardly a commercial crop and there is no prospect of income. It is true that this makes it no different to Souna as millet is mainly for on-farm consumption (only possible surpluses are sold, generally in small quantities on the local market) but this is no ‘compensation’ for the production risks.

To conclude, it should also be stressed that the renewed growing of Sanio does not involve any particular problems for farmers as no technical or technico-economic switch is involved, unlike watermelon, rice and even maize, and it does not have any particular labour requirements. Sanio can be sown dry like Souna using the same draught seeder and even simultaneously if the two are grown as companion crops (farmers first sow rows of Souna and then rows of Sanio) (Fig. 3c). Neither variety requires any particular inputs or pesticide treatment.

However, farmers recognise that they have certain difficulties in growing Sanio and consider it to be ‘more tiring’. Indeed, the crop requires a return to the fields at the end of the season when the other jobs have been completed but the harvest is not in competition with the others. Some farmers say that a Sanio fields crop requires three hoeings instead of two, although others say the opposite a ‘Sanio covers the ground well’ and that ‘this depends on row spacing’. It also appears that farmers harvest it in two passes, first to gather the best ripe spikes and then a second time. Finally, it seems that harvest is more difficult—’unpleasant’—as the spikes are aristate and could wound hands and especially eyes (the bristles become detached and can be blown) even though there are harvesting techniques in which the worker can protect himself and then remove the bristles easily by running the spikes on the ground. Women also pointed out that crushing Sanio is difficult and unpleasant if the bristles have not been removed before the storage of the spikes. There is no doubt that the lengthening of the working season and perhaps the comparatively hard harvest that explain why 89% of the farmers questioned in the Niakhar region said that Sanio requires a lot of labour. This is also said by farmers in interviews: ‘It is tiring to carry on working hard late in the season when all the other jobs are finished’.

Finally, there are no particular problems even if growing Sanio again involves the discovery of a few 'new' hardships and lengthens the working season. All that is necessary is a supply of seed and to decide to devote land to it.

Continued Sanio cultivation areas from which seed has been distributed for 10 years

The Sanio distribution area (Fig. 6a) shows a recent distribution process that seems to be centred on two groups of villages where this variety has always been grown in spite of the decades of drought: the area around the village of Diakhao—former capital of the Kingdom of Sine—and the zone lying between the villages of Ngayokhèm and Niakhar. Sanio spread strongly from these two areas from the beginning of the 21st century, extending to the north (Bambey and Diourbel) and west (Fissel). Thus in 2013 it was grown in 61% of the 240 sites covered by our light geographic survey whereas it had been present at only 23% of the sites in 2000 (Fig. 6a).

We were surprised to observe the continued attachment to this grain in a large number of villages, with its uninterrupted presence mentioned for 45 of the 240 sites (19%) of our light survey (Fig. 6a) and in 14 of the 30 villages (47%) of the questionnaire survey, although this was conducted in one of the two areas (Fig. 6b). However, very few farmers in these villages continued to sow Sanio. In Ngayokhèm, where four out of five farmers (78%) were growing Sanio again in 2013, we identified only three farmers who had grown and conserved it during the dry decades.

The few farmers who continued to grow Sanio in spite of shortage of rainfall refer to extraordinarily simple reasons and techniques. Amadou Diouf, a Serer farmer in the village of Ngayokhèm who said that he had always grown Sanio, explained that he always sowed a minimum of a few rows of Sanio between rows of Souna and that he always had enough seed for sowing again in the following year without having to search for another source of supply. His grain production was rarely sufficient for consumption but 'there were the stems' that are 'very good for fencing' and there was always the hope that 'there might be good production again one day'. Even if no farmer put it this way, their statements—like that of Amadou Diouf—indicate strong attachment to this millet variety whose qualities they firmly recognised.

Of course it is possible that in some years farmers had to obtain Sanio seed from the south, either by going to purchase it or by gifts or exchanges with farmers—relatives or not—in the Saloum or the 'new lands'. But the strategies described by Serer farmers show their determination not to lose traditional millet varieties.

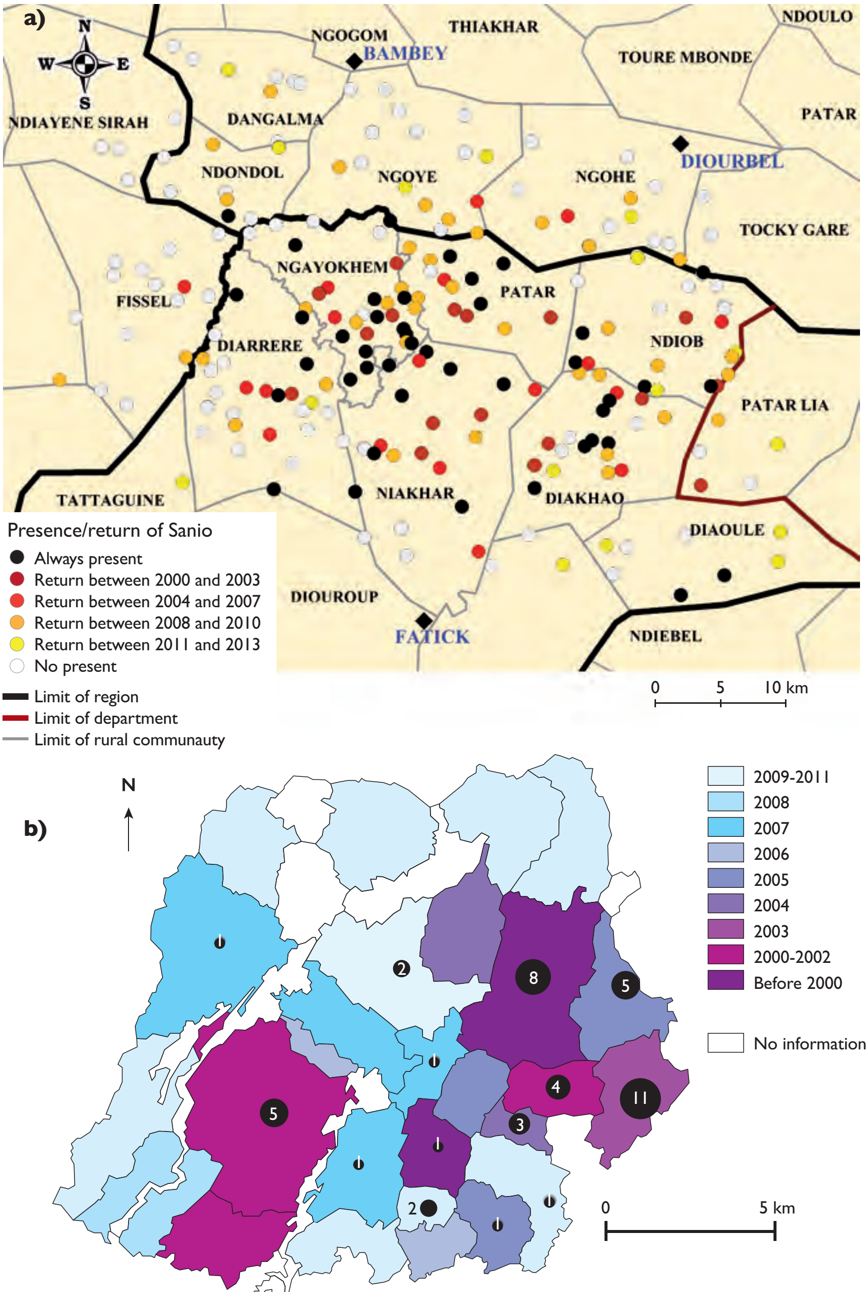

Figure 6.
(a) The presence and year of return of Sanio in the region (light geographic survey, ESCAPE 2014); (b) year of recent resumption (after 2000) of Sanio growing in the villages in the Niakhar zone and villages identified as having always grown this crop (the number of persons surveyed who made this declaration is indicated in black circles (questionnaire survey, ESCAPE - 2013/2014).

The recovery of rainfall: a necessary condition but not enough for the recovery of Sanio

In the Niakhar survey zone, 270 of the 1,061 farmers questioned (25.4%) chose to grow Sanio in 2013. However, only 89 (14%) of the 630 fields concerned by Sanio were sown with Sanio alone as a field crop. The majority were sown with a combination of Souna and Sanio with fewer rows of Sanio, generally with 1 row of Sanio to 5 rows of Souna. Thus in 2013 Sanio was only grown on 2.8% of the farmed area in the Niakhar zone and formed 7.3% of the area under millet. Sanio as a sole crop was grown only on 1.2% of the farmed area (Fig. 7a). For growers of Sanio (25.4% of farmers using 28% of the area), Sanio was on 10% of the sown land and on 27% of the area devoted to millet as sole cropping as a field crop concerned 29% of the fields sown with Sanio while it was combined with Souna in two fields in three. As in the past, Sanio is generally sown in bush fields (85%) and in sandy soils (75%) with little or no manure (86%). These figures show that the return of Sanio is still uncertain and fragile and that it is mainly grown in association with Souna.

There is no doubt that sufficient rainfall staggered over nearly four months is needed to achieve a Sanio millet yield to allow regular consumption by the household. And in fact the spread of Sanio among farmers only started after the recovery of rainfall at the beginning of the 2000s. However, although all the farmers and villages in the Sine are subject to the same climatic conditions and although most have observed the recent increase in rainfall depths (see Chap. 4), they have not all resumed Sanio growing or taken it up again with the same intensity. The return of the rains has increased the number of strategies available for farmers but without imposing choices.

The heterogeneity of cropping behaviour is first of all geographic. As is shown in Figure 7b, in 2013 not all the villages in the Niakhar district covered by the survey have undertaken Sanio growing in the same way. Overall, the majority of the villages in the south (12/21) have grown Sanio in above-average proportions (26%). In the 21 villages in the south, an average of 43% of the farmers grew Sanio in 2013 while in the north (9 villages) the proportion fell to 5.5%. In the south, Sanio growing decreases in intensity along an east-west gradient, reminiscent of the dynamics of the penetration of this millet variety in the Niakhar district (Fig. 6b). The villages in which most Sanio is grown are located mainly around Ngayokhèm and Sass Ndiafadji. The villages in the north, where little Sanio is grown, adjoin the historic territory that used to be the Kingdom of Baol (where Wolof presence is more marked). Clayey soils are more common in the zone, beef fattening is an important activity, non-agricultural work with a cash income is more common and all linked with seasonal migration, and stronger Mouride influence.

As between villages, clear differences are seen between farms. The global logistic model of the factors associated with Sanio growing in 2013 (Table 1) shows first of all that at the beginning of the 21st century growing Sanio is for some people a heritage and memory, that of men and women and the agrosystem. Thus nearly twice as many farmers whose fathers had grown Sanio in the past grew it than farmers who did not have this family tradition (OR = 1.78; p = 0.014). This cultural dimension also appears when Sanio growing is analysed according to the main caste of the household. Thus growing Sanio is significantly more widespread among 'noble warriors' than among 'farmers' (OR = 2.88; p = 0.0001) and it is less frequent among 'griots' (OR = 0.13; p = 0.008). These correlations should be seen as the trace of pre-colonial division of labour that forms the basis of the caste system (C. A. Diop, 1960). The noble warriors were the guardians of tradition and land

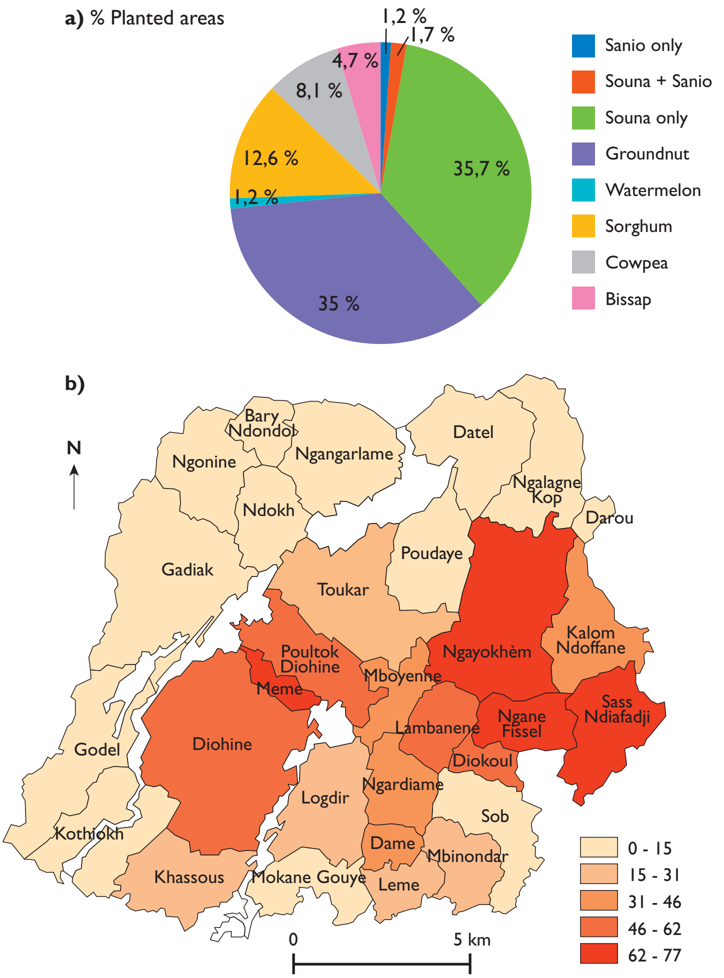

Figure 7.
(a) Percentages of planted areas by crop in 2013 (questionnaire survey, ESCAPE - 2013/2014);
(b) proportion of farmers who grew Sanio in-2013 (questionnaire survey, ESCAPE - 2013/2014).

while for reasons of their function as keepers of oral tradition (history, genealogy) the griots were excluded from agricultural activities. Finally, it is noted that the fewer of the men in the household have made long stays outside their territory (seasonal migration), the more the household in question is likely to grow Sanio (OR = 0.997; p = 0.035).

However choosing Sanio also—and above—all depends on land resources. It is more commonly grown when the farmer has sufficient land (OR = 1.16; p = 0.001), and Sanio growers have an average of 4.9 ha against 4.2 ha for the others. In addition, more farmers who borrowed land in 2013 sowed Sanio than the others (OR = 1.73; p = 0.0011). These features are corroborated clearly by farmers, who explain that they do not replace fields of Souna by fields of Sanio and that 'before growing a field crop of Sanio you have to have enough fields of Souna' to cover household food requirements and also have available land.

As has been mentioned above, although farmers consider that 'Sanio' is a crop that requires more labour as, in particular, it makes the agricultural work season longer, shortage of labour does not seem to be a significant obstacle to the crop (Table 1) as neither the size of households nor the return of migrants to help with crops during the rainy season increase the chances of growing Sanio. This is doubtless related to the fact that the extra work involved in the Sanio crop does not coincide with work on the other crops. However, it is noted that the number of persons who can help with agricultural work (6-year-olds and over) is significantly greater in the households where Sanio has been grown (9.4 persons) than in the other households (8.8 persons).

Absolute poverty (food or monetary poverty) is generally considered to be a barrier to adaptation to climate change. However, in the present case in which adaptation (i.e. growing Sanio millet) is reactive and consists of profiting from a climatic opportunity, monetary poverty is far from preventing it and in fact favours it (OR = 1.95; p = 0.002). This counter-intuitive relation can only be explained by the fact that growing Sanio requires no additional investment and no particular technical resources.

Finally, it is observed that households managed by women grow less Sanio than those managed by men (OR = 0.53; p = 0.023).

Applying similar modelling to the 21 villages in the south of the observation zone shows overall the same causal relations as in the overall model (Table 1) but with a noteworthy difference: growing Sanio may compete with other agropastoral production. Thus beef fattening reduces the chances that a farmer might choose Sanio (OR = 0.91; p = 0.030). Likewise, there is little chance that the same farmer will grow watermelon and Sanio (OR = 0.52; p = 0.052). This is explained by the need to reserve a field for watermelon[9]. Indeed, when he can a farmer opts for the economically most profitable choice. The options—in contrast with Sanio—beef fattening and watermelon (both for the sale of production)—doubtless explain

9. Indeed, watermelon is sown at the end of August/beginning of September so that growth profits from rainfall and fruit development takes place under dry conditions using soil moisture. It is not possible to grow watermelon after Souna (or groundnut) and even less after Sanio.

Table 1.
Analysis of the factors associated with Sanio growing by farmers in the Sine.
Logistic regression applied to 1,061 farms
(questionnaire survey, ESCAPE - 2013/2014).

	Modèle global		**Modèle villages sud**	
	Odds Ratio	**P>z**	**Odds Ratio**	**P>z**
Number of observations (total ;Yes ; No)	(518 ; 257 ; 261)		(501 ; 246 ; 255)	
Did the farmer's fther grow Sanio?	1.779	0.014	1.931	0.005
Sex of the head of the household	0.527	0.023	0.535	0.029
Number of adults who returned to the village during the last rainy season	0.860	0.572	0.750	0.290
Proportion of workers with extra-agricultural income	0.942	0.558	1.027	0.799
Proportion of adult household members managing one or more fields	1.002	0.962	1.066	0.058
Beef fattering	0.956	0.302	0.910	0.030
Watermelon	0.664	0.284	0;515	0.052
Area in hectares	1.157	0.001	1.117	0.009
Number of persons old enough to participate in farmwork (6-year-olds and over)	0.996	0.894	0.974	0.360
Borrowed lan	1.726	0.011	1.886	0.003
Average duration of seasonal migration by adult men (15-55 years old)	0.997	0.035	0.999	0.472
Majority caste of members of the household				
Farmer	Ref.		Ref.	
Tiedo	2.884	0.000	1.234	0.361
Griot	0.127	0.008	Pas d'observations	
Monetary poverty	1.946	0.002	1.489	0.058
Constant	0.395	0.128	0.626	0.453
Pseudo-R2	0.121		0.069	
Roc curve	0.717		0.676	
Hosmer-Lemeshow test (prob. value)	0.703		0.814	

why the households that are the least poor in monetary terms are those that grow Sanio least (Table 1). Questioned about the reasons for Sanio being particularly strongly present at Ngayokhèm where watermelon was not grown, in contrast with the neighbouring village of Sob, farmers at Ngayokhèm clearly pointed out the financial advantages of watermelon over Sanio and added that unfortunately 'the large urban markets for watermelon have been taken by the people of Sob where all the lorries stop now without wanting to go any further'. And several of them added that they would stop growing Sanio if there were other more profitable options among crops.

Conclusion : adaptation to climatic evolution whose future remains uncertain

The recent spectacular return of Sanio in the Serer landscape of the Sine is clearly a 'marker' of the recent evolution of rainfall observed in Senegal and West Africa (SALACK *et al.*, 2011; SÈNE and OZER, 2002; OZER *et al.*, 2003). Indeed, it is clearly the return of rainfall, especially at the end of the rainy season, which makes it possible to grow this relatively long-cycle millet again in a semi-arid area from which it had practically completely disappeared after the major droughts of the 1970s and 1980s.

Its steady, very large geographic spread throughout the last decade is explained by the fact that it is easy to grow if land is available for it and by the recognised qualities of its grain and stems. It thus appears as an adaptation to the climate that draws benefit from long rainy seasons by giving farmers a new option in their cropping strategies. But Sanio growers are also aware of the considerable climatic risks involved in production, to which are added pest risks. Reintroduction is thus being handled cautiously and without compromising the food balance of households. Thus no farmer is replacing Souna by Sanio and the farmers growing Sanio (especially as a single field crop) are those who still have land available after sowing Souna. In addition, Sanio does not bring in income. So as is shown by the small areas devoted to it in spite of its presence on a growing number of farms, it is still a secondary grain crop—far behind Souna (and sorghum).

A parallel must be made here between the recent expansion of watermelon in certain villages in the Sine and elsewhere, and of maize and upland rice in the Saloum and in Casamance. Like Sanio, watermelon makes it possible to benefit from fairly rainy ends of seasons. So it has appeared in the Sine. But unlike Sanio it is a delicate crop that requires investment in seed, inorganic fertiliser, pesticides (essential) and apparatus (sprayers) and good technical skills. In return, it gives substantial returns on a market that is nonetheless very volatile and a priori becoming saturated.

Further south, especially in the Saloum around Nioro du Rip, maize has developed spectacularly thanks to increased rainfall while Sanio is practically totally absent. Maize had decreased very strongly in the region since the 1970s and is now grown on 25% of the area devoted to grain crops—with Souna millet being dominant—and has even become integrated in local food habits (eaten mixed with millet). Farmers grow it intensively using ploughing (increasingly with a tractor) and purchasing certified seed of improved short-cycle varieties (80-90 days), or even hybrids, and using large amounts of fertiliser. For this, they benefit from active farming associations and the development of an increasingly well-organised sector supplying agroindustries in Dakar, enabling increasing replacement of imports by local production.

Finally, still further south, upland rice is developing strongly, once again because of the increase in rainfall and also because of strong demand for this grain in Senegal—still relying too much on imports—and the distribution of 80-90-day early varieties of the NERICA type. Upland rice production is even starting to spread to the Saloum.

The return of Sanio millet, like the increase in watermelon and the development of maize and upland rice—all made possible by the recent increase in rainfall—shows the tremendous capacity of farmers to adapt rapidly to changes in their environment, sometimes even before accompaniment by the research sector, by always seeking to profit from all opportunities but never taking risks that would endanger their food security, which remains based on Souna.

The future of Sanio is uncertain for the same reasons. Its presence will probably decrease if other more profitable opportunities arise and even more certainly is rainfall were to decrease again. To enhance its maintenance, the development of a small '*Matye*' sector based on grain quality and its traditional image could be developed. But given the uncertainties weighing on the climate in the Sine, this could be of more benefit to farmers further south. There remains the possible solution, requested by farmers, of developing 'Sanio with a shorter cycle' that would reach maturity after 3 months (like Souna) and have the much appreciated features of the aristate heads, nutritive and tasty grain and excellent forage stems and straw of '*Matye*'.

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Chapter 19

Reintroducing livestock to increase the sustainability of village landscapes in West Africa

The case of groundnut basin in Senegal

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Introduction

In West Africa living conditions and food security improvement are still key issues (Lahmar *et al.*, 2012). Farming systems sustainability is a priority in a context in which the rural population is dominant. Traditionally, integrated agro-sylvo-pastoral systems are in the majority in West Africa (Dugué *et al.*, 2012; Jouve, 2001). They are based on the complementarity of ruminant herds and flocks of ruminants, cereal crops and trees (Jouve, 2001). The sustainability of these systems depends to a considerable degree on transfers of fertility from rangelands to cultivated fields via the night corralling of livestock (Freschet *et al.*, 2008; Jouve, 2001). Among other things, these agrarian systems have had to adapt to changing rainfall patterns and strong demographic growth. Indeed, West Africa experienced a long drought period from 1970 to 1995 (Cormier *et al.*, 2000) and the population doubled during the same period (Dongmo *et al.*, 2010; FAO, 2003; Serpantié and Ouattara, 2001). In reaction to this and to respond to increasing food requirements, rural populations have cultivated marginal land (Courtin and Guengant, 2011; Faye and Landais, 1986; Schlecht *et al.*, 2004). These areas were traditional used for grazing. The extension of cultivated land has therefore resulted in a reduction of herbaceous fodder resources and has increased the pressure on wooded areas, especially in dry years. There was particularly strong pressure on the wooded areas during the 1970-1995 drought period, resulting in regression caused by over-exploitation (Courtin and Guengant, 2011; FAO, 2003). As a result, the number of head of livestock decreased and feed was refocused on crop residues, increasing the tensions centred on this resource (Freschet *et al.*, 2008; Jouve, 2001; Rufino *et al.*, 2010). The current trend is that of harvesting residues (Faye and Landais, 1986). They are collected for sale or storage to cover the feed requirements of livestock during the dry season (Dugué, 1985; Fall-Touré *et al.*, 1997; Schlecht *et al.*, 2004). It results from a switch from a collective management system to an individual one (Courtin and Guengant, 2011; Dugué, 1985; Jouve, 2001). The decrease in the presence of livestock combined with the harvesting of crop residues (in addition to the crop main product itself) affects soil fertility as exports of nutrients are no longer compensated by equivalent input in the form of manure (Buldgen *et al.*, 1992; Dugué, 1985; FAO, 2003).

In this study we examined the case of the Sereer populations in the Senegalese groundnut basin. Whereas the landscape already seemed to be saturated in 1960 (Lericollais, 1999), the population of this part of Senegal doubled from 1963 to 2009 (Delaunay and Lalou, 2012). Adaptation strategies differed according to the village (Dugué, 1985). Their common feature is the increase in the transhumance of cattle. In order to keep livestock in village landscapes, called *terroirs* (see below for definition), some village communities have kept the common fallow while others have developed fattening operations. One might then wonder whether, in a context of landscape saturation and strong climatic variability, an intensive system based on the reintroduction of cattle through fattening is more sustainable than the traditional extensive cattle farming based on a fallow system. To answer the question, we compared two village landscapes that use these different agricultural strategies (fallow versus fattening) in the same soil and climate zone.

Material and method

The conceptual model guiding analysis

The conceptual analysis model is of the stock-flow types in which three systems are embedded: *terroir*, household unit and field (Fig. 1). These different systems are crossed by incoming and outgoing flows of biomass. The biomass consists of the main materials circulating in the farming systems studied (Fig. 1), i.e. the main production of the tree layer, crops (grain, residues, etc.) and livestock (manure, animals, milk, etc.) together with the main inputs (mineral fertiliser, concentrated feed, foodstuff, etc.).

The system studied: the village *terroir*

Favouring a systemic approach, we chose the ‘Africanist’ definition of *terroir* as ‘an area cultivated and used by a village community’ (Rabot, 1990). A *terroir* can be divided into landscape units that make it possible to model the spatial organisation of biomass and nutrient flows (dwelling zone, compound fields, bush fields, rangelands reserved for livestock) (Lericollais, 1999; Manlay, 2001; Tittonell *et al.*, 2006).

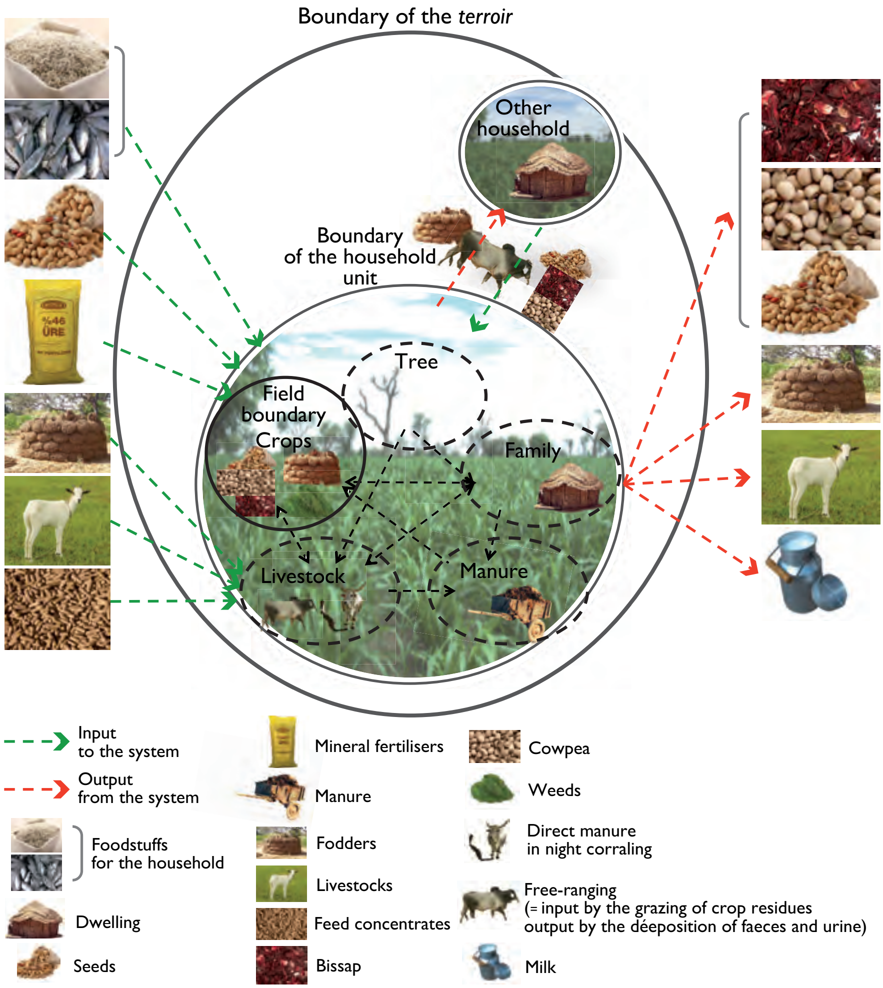

Figure 1.
Conceptual representation of the system studied in three embedded systems (the terroir, the household unit, and the field).

This study is focused on two *terroirs* close to each other (about 8 km apart) in the same soil and climate zone in the Senegal groundnut basin (average rainfall 566 mm.year^{-1}, Fatick meteorological station, 2013). Diohine, the first *terroir*, features a farming system with a traditional trend and based on a common fallow. Barry Sine, the second *terroir*, displays a spectacular increase in livestock fattening (Fig. 2).

Household and field units

Historically, the Sereer are gathered by family membership within a holding. Each holding is a dwelling unit and generally consists of several households. Whereas

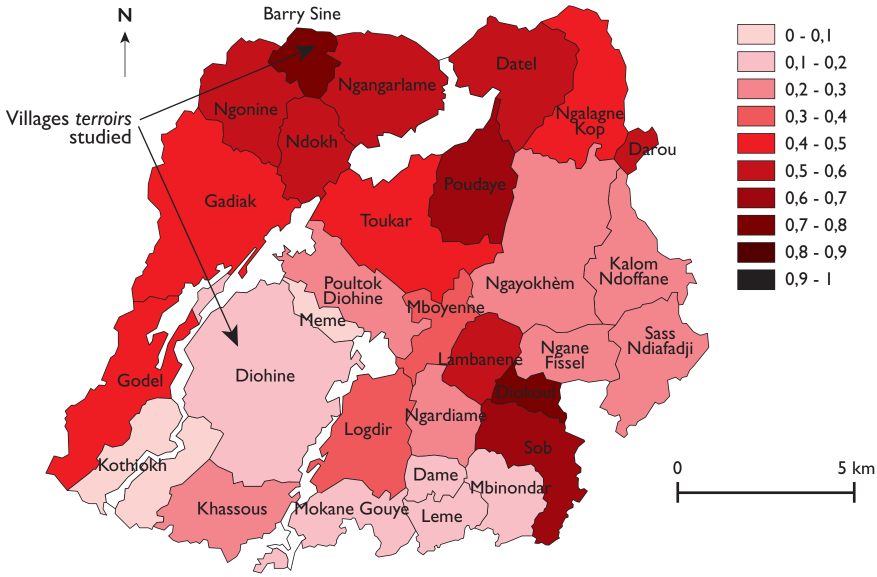

Figure 2.
Frequency of holdings carrying out fattening in 2012
in the various village terroirs of the IRD HDSS observatory at Niakhar
(Source: Delaunay and Lalou, 2012).

historically most decisions were taken at the scale of the holding, the household is now usually the main decision unit for the management of agricultural resources (livestock, land, equipment, etc.). The household can be divided into five sub-systems or farming 'workshops': family, crops, livestock, effluent and the tree area (see Fig. 1).

The field is the crop management unit. This sub-system is conventionally considered in studies on the evaluation of the sustainability of farming systems as in agronomy it is the classic scale for the evaluation of crop yields and fertility balances (Schlecht and Hiernaux, 2004).

Data gathering and field units

Household surveys

The aim of the surveys was to describe the structure and farming practices of each household. The exhaustive list of the households in each village and the corresponding demographic data are from the Niakhar observatory database (Delaunay *et al.*, 2013). Agricultural practices have been converted into biomass flows between the various farming workshops to calculate sustainability (see below). The survey guide was therefore divided according to the 5 agricultural workshops that generate biomass flows (see above). Incoming and outcoming flows were quantified for each workshop (Fig. 1). The reference year was the 2012 farming season (June 2012 to May 2013).

Inter-household flows were also recorded. These consist of commercial flows of biomass (information drawn directly from surveys) and the flows generated by herds and flocks. Calculation of the latter flows is detailed below (SCHLECHT *et al.*, 2004; THORNTON and HERRERO, 2001).

Biomass flow database

The database of biomass flows is compiled in standard units (kg FW and kg DM). Local units (carts, bundles, etc.) were converted into standard units by weighing during the study or using conversion factors available in the literature (VANDERMEERSCH *et al.*, 2013).

Flows that could not be quantified directly by a survey, that is to say inter-household flows via flocks and herds, were calculated according to the different practical seasons (see below).

In the dry season after the harvests, livestock ranges freely in the fields and eats crop residues left in the field. Part of the biomass is then returned as faeces and urine. The same applies in the rainy season when livestock grazes fallows (the case at Diohine).

Biomass ingestion flows are calculated according to the fodder available for each household. This is production in household's fields with deduction of the household's harvest and consumption by the household's livestock (according to flock and herd size and the feed practices). If the balance is positive, the surplus is used by the livestock of a household with a shortage. If it is negative, it is counter-balanced by using quantities from the fields of households with surpluses.

Return in the form of animal faeces and urine was calculated using the duration of presence of batches of livestock in Tropical Livestock Units (TLU.h) in the various landscape units and in the different fields for each relevant season (SCHLECHT *et al.*, 2006).

Spatialisation of flows and stocks using a geographic information system

We chose the spatial approach to biomass flows since movements of nutrients in the landscape form an essential component of the maintenance of soil fertility in the Sudan-Sahel zone (RABOT, 1990). Each field was therefore georeferenced. The different flows and balances calculated for the area of each field were then spatialised to represent flow distribution in the *terroir* in order to evaluate the landscape units that form fertility sources or sinks (MANLAY *et al.*, 2004; DUGUÉ, 1985; TITTONELL *et al.*, 2006).

Calculated sustainability indicators

The research conducted in West Africa over the past 30 years has shown that nutrients, and especially nitrogen, form a major limiting factor for agricultural productivity (RUFINO *et al.*, 2009; SCHLECHT *et al.*, 2006). The nourishment of grain crops in sandy tropical soils in West Africa is based mainly on the extraction of organic nitrogen from the soil—finite reserves with a limited quantity (WANEUKEM and GANRY, 1992). Because of the dominant role of nitrogen in the farming systems in the zone studied, we chose this element to construct our main sustainability indicators. Thus, biomass flows (in kg $DM.year^{-1}$) were converted into nitrogen flow (in kg $N.year^{-1}$). The four indicators below were calculated at three levels (field, household and *terroir*) for better understanding of the functioning of the two *terroirs* studied.

Nitrogen balance

Agricultural intensification can endanger the sustainability of a farming system if it is not coupled with maintaining soil fertility. The nutrient balance is hence a useful indicator of the sustainability of the system (ROY *et al.*, 2005; THORNTON and HERRERO, 2001). Only the apparent N balance has been calculated here. It is the difference between N inputs and outputs calculated for the agricultural area in use (AA). It does not include vertical flows (gas emissions, symbiotic fixation, atmospheric deposition, etc.).

Nitrogen use efficiency

A second evaluation of system sustainability can be performed using N use efficiency. This indicator is calculated by dividing N outputs by N inputs. It indicates the 'return on investment' as it shows how many N units are produced for each unit used (VAYSSIÈRES, 2012).

Productivity

The food security of households remains the main preoccupation of the Sereer. Examining the productivity of farming systems is therefore essential for defining sustainability. The indicator is in kg $DM.ha^{-1}.year^{-1}$, kg $N.ha^{-1}.year^{-1}$ and kg $N.inhabitant^{-1}.year^{-1}$. It can be calculated at the three levels. At field level it is crop yields.

Imports

Imports in a *terroir* or household reveal the dependence of the system on other systems. They also show the independence of the system with regard to climatic events and the degree of pressure on local natural resources (e.g. wooded areas). The indicator can be expressed in kg $N.ha^{-1}.year^{-1}$ or kg $N.inhabitant^{-1}.year^{-1}$ (RUFINO *et al.*, 2009).

Results

Village structure

DWELLING AND LAND USE

Diohine is an old village in which dwellings are concentrated and organised in districts. The dwelling pattern in Barry Sine is the result of numerous relatively recent population movements and is fragmented and dispersed (Fig. 3). There is thus a 'district hierarchy' in Diohine while there is a 'holding hierarchy' in Barry Sine.

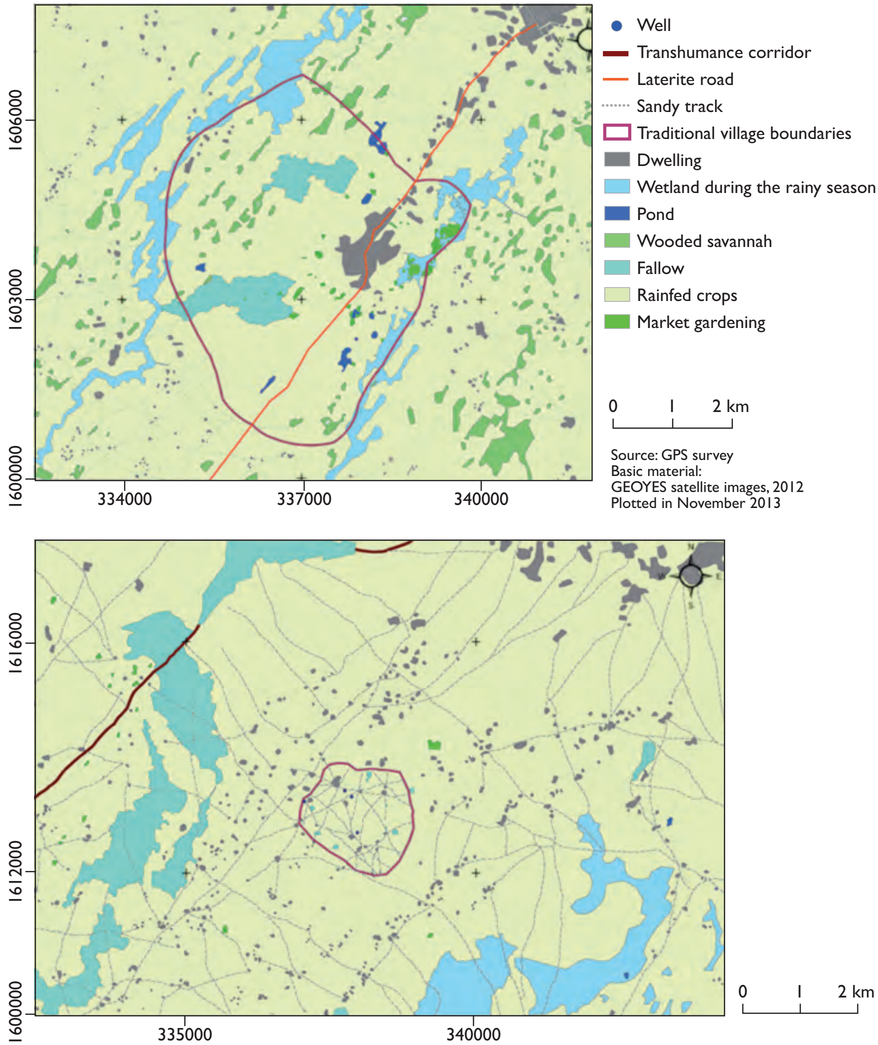

Figure 3.
Agro-ecological zoning of Diohine (top) and Barry Sine (bottom) in 2013.

Diohine displays a pattern of organisation that is more similar the traditional model organised around the lowlands that are essential for maintaining livestock in the *terroir*. In contrast, Barry Sine has no lowland, ponds or tree savannah within the traditional village limits.

Human and animal populations, land available and rotations

Population pressure (180 inhabitants.km^{-2} in Diohine; 320 inhabitants.km^{-2} in Barry Sine) and the livestock stocking rate (0.96 TLU.year.ha^{-1} in Diohine; 2.31 TLU.year.ha^{-1} in Barry Sine) are smaller in Diohine. The latter village has conserved an extensive free-ranging livestock system. Livestock grazes on 20% of the UAA under fallow for this purpose during the rainy season. In contrast, Barry Sine has only a few isolated fields under fallow and has developed intensive livestock farming with substantial imports of concentrated feed.

Millet is still the main crop in both *terroirs* using 53% and 55% of the UAA in Diohine and Barry Sine respectively. Groundnut decreased in Diohine where it now uses only 7% of the UAA in comparison with 30% in Barry Sine (Fig. 4).

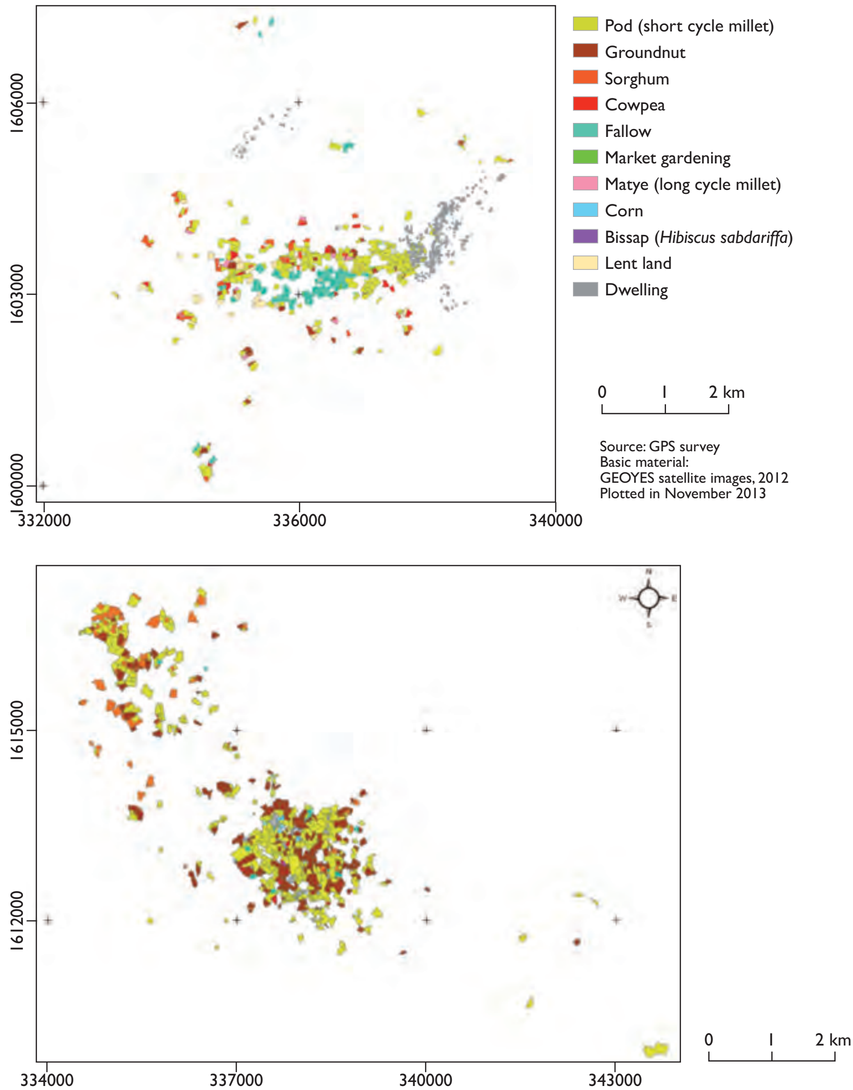

Figure 4.
Cropping land use maps of Diohine (top) and Barry Sine (bottom) in 2012.

Diversity of households

The households in the two *terroirs* were classified in 5 types according to structural data and farming practices (Table. 1). The patterns are uneven.

Table 1.
Characteristics of the different types of household.

Class	1- Newly installed	2- Subsistence farmers	2'- Cash crop farmers	3- Traditional mixed farmers	3'- Fatteners
Livestock stocking rate (TLU.ha^{-1})	1.3	1.3	3.1	3.6	3.7
Fattening livestock stocking rate (TLU.ha^{-1})	0.3	0.2	1.0	0.1	2.2
Population (inhabitant.ha^{-1})	4.5	2.8	4.2	3.1	6.3
UAA (ha)	3.8	5.5	5.2	5.3	4.9
Area under groundnut (%)	26	19	32	8	20
Area under fallow (%)	2	11	2	19	0
Proportion of Diohine households (%)	11	78	0	11	0
Proportion of Barry Sine households (%)	26	49	19	0	6

The best-represented type of household is in the 'Subsistence farmer' category, especially in Diohine. The second type is the 'Newly installed' category, especially in Barry Sine where this is more individualisation of households. Young heads of household have little UAA and few livestock and are particularly dependent on the resources of the *terroir* (grass and wood).

The 'Traditional mixed farmers' that is found only in Diohine consists of heads of holding who have kept a large proportion of fallow and manage medium-sized traditional and transhumant herds and flocks.

'Cash crop farmers' and 'Fatteners' are only found in Barry Sine. Both focus on commercial production (groundnuts and fattening). The 'Fatteners' type consists of densely populated households with little UAA.

'Fatteners' have a high TLU ratio in comparison with total TLUs. In contrast, there is little or no fattening in 'Traditional mixed farmers'. Both types have the feature of making little plant biomass (crop residues) available to the flocks and herds of other households as their stocking rate is high.

Thus the flocks and herds in 'Traditional mixed farmers' also graze in the fields of other households and in particular in those of 'Subsistence farmers' who have low stocking rates. These farmers thus draw on nitrogen in the fields of other households and that they concentrate in their own fields by night corralling. However, they loan their livestock for corralling, especially to the 'Newly installed' category and can thus increase their UAA by borrowing manured fields in the following year (Odru, 2013).

In contrast, 'Fatteners' tend to keep livestock hobbled in the holding that does not participate in free ranging. To feed these animals, the households gather a large proportion of residues on their own fields and also sometimes purchase residues from other households in the 'Subsistence farmers' and 'Newly installed' categories.

Farming practices and equipments

The hinging of livestocks and crop farming

The types of dominant households in each of the two *terroirs* are different. The different practices that result can be described with a distinction made between the main seasons related to crop management and livestock.

The rainy season and the beginning of the cold dry season (R1, R2 and CD1) form a period during which livestock and crop farming may compete with each other. As a result, part of the 'free-ranging ruminants' (cattle, goats and sheep) leave for transhumance to Saloum and then Ferlo (0.11 $TLU.ha^{-1}$ in Diohine and 1.10 $TLU.ha^{-1}$ in Barry Sine). Competition between activities is reduced in Diohine thanks to common fallow and access to the lowlands, making it possible to keep more head of livestock in the *terroir* (0.56 $TLU.ha^{-1}$ in Diohine; 0.35 $TLU.ha^{-1}$ in Barry Sine). This is not the case in Barry Sine, where more fattening is carried out (0.01 $TLU.ha^{-1}$ in Diohine; 0.57 $TLU.ha^{-1}$ in Barry Sine). This type of livestock farming reduces relations between livestock and crop farming as the animals are hobbled within the holding and feed is strongly based on concentrates purchased from merchants and feeds imported in the village *terroir* (e.g. complete concentrated feed, millet bran, rice bran, etc.).

At the end of the cold dry season and during the hot dry season (CD2, HD1, HD2 and HD3), crop and livestock farming become potentially complementary as soon as the by-products are collected. Indeed, the free-ranging livestock graze crop residues in the field and are paddocked at night in certain fields. The hot dry season in Diohine is more split than in Barry Sine, with two distinct lean periods (HD2 and HD3). In the first phase, 'free-ranging ruminants' have access to common grazings, feeding in priority on crop residues left in fields and the resources of the lowland (Odru, 2013). In the second phase, fodder is based on stored crop residues and trimmings from fodder trees (e.g. *Faidherbia albida*).

The sheep fattening period generally aims at Muslim festivals such as 'Tabaski' (Eid al-Adha) while beef fattening is spread over the dry season each year for the production of counter-season meat. The 'finishing' type of beef fattening is performed in Diohine; just a few head of cattle are taken from the free-ranging herd for fattening. In contrast, 'purchase/resale' fattening is carried out in Barry Sine.

Fertilisation of cultivated land

The nutrient flows generated by herds and flocks (during free-ranging, rainy season grazing and night corralling), manure and mineral fertiliser are the principle field inputs.

	May	June	July	August	September	October	November	December	January	February	March	April
Climatic seasons	Cold season			Rainy season			Cold dry season				Hot dry season	
Pratical seasons in Diohine	HD3			R1			CD1	CD2		HD1		HD2
Practical seasons in Barry Sine	HD3		R1		R2		CD1	CD2		HD1		
Collective fallow grazing period in Diohine			++	++	++	++	++	++				
Millet cropping	+	++	++	++	++	++	++	++	+			
Groundnut cropping		+	++	++	++	+						
Presence of transhumant livestock	+	+					+	+	++	++	++	+
Bovine fattening	++	++	+				++	++	++	++	++	++
Ovine fattening		+	+	++	++	++						
Cultural events in 2012			Korité	x	Tabaski	Tamkharit x	x	Magal	x			

Seasonal units:
R1: Crops sown and fodder harvesting (fresh)
R2: Ovine fattening
CD1: Harvesting main crops
CD2: Harvesting by-products + free-ranging with a shepherd
HD1: Full free-ranging season
HD2: Lean period with resources from lowland
HD3: Lean period with feed supplements + land preparation

Figure 5.
Representation of the pattern of practical seasons in the two village terroirs.

Free-ranging, rainy season grazing and night corraling

At field level, the contribution of free-ranging livestock forms 32 and 15% of total N input in Diohine and Barry Sine respectively. A large proportion of by-products is left for livestock in Diohine and the withdrawal of plant biomass exceeds the deposition of faeces and urine. It results in nitrogen export of -8 $kgN.ha^{-1}$ in the dry season during common ranging and -26 $kgN.ha^{-1}$ in the rainy season during grazing of common fallow. In Barry Sine, common ranging generally fertilises the land (+5 $kgN.ha^{-1}$) as the stocking rate is high, most of the plant biomass is harvested and the livestock has substantial complements.

As a result of the maintaining of livestock during the rainy season thanks to fallow, night corralling of this season is applied in an area 10 times as large in Diohine (2.7% of the UAA in Diohine, 0.2% in Barry Sine) and more intensively in Diohine (manure deposition 3.95 t $DM.ha^{-1}$ in Diohine and 1.75 t $DM.ha^{-1}$ in Barry Sine). The opposite is observed for night corralling during the dry season. It is used 10 times more in Barry Sine (3% of the UAA in Diohine and 39% in Barry Sine) and is applied to all types of fields, however remote they are from the dwelling, where it is only used in compound fields in Diohine (Fig. 6). The average quantities of manure deposited in the dry season are higher in Barry Sine (2.40 t $DM.ha^{-1}$ in Diohine; 2.57 t $DM.ha^{-1}$ in Barry Sine).

Manure application

Manure forms 14% of nitrogen input in Diohine and 12% in Barry Sine. In both villages, manure spreading is performed in priority in compound fields in accordance with the traditional pattern. In contrast, the agricultural equipment in Barry Sine means that a large proportion of the UAA can be manured (Fig. 7).

Average manure spreading is fairly similar in both villages (1.69 t $DM.ha^{-1}$ in Diohine; 1.64 t $DM.ha^{-1}$ in Barry Sine). However, the households in Barry Sine are better equipped with carts (48% of Diohine households have a cart in comparison with 86% in Barry Sine). Better equipment combined with greater availability of manure means that the latter can be better distributed in space (manuring covers 24% of fields in Diohine and 31% in Barry Sine).

Application of mineral fertiliser

The spreading of mineral fertiliser is not directly related to livestock farming but plays a preponderant role by supplying the greater proportion of nitrogenous inputs in the fields at Barry Sine (8% in Diohine; 26% in Barry Sine). Mineral fertiliser is spread on a larger area in Barry Sine (2% in Diohine; 27% of the UAA in Barry Sine) and in higher doses. Thus the village counterbalances application of organic fertiliser (faeces and manure) favoured for compound fields by the application of mineral fertiliser in priority in the bush fields (Fig. 8).

Crop management and yields

Following analysis of the main inputs in fields, we now describe their impact in terms of yield. Yields of cereals are greater in Barry Sine and similar for groundnut in both villages (Table 2). It is noted that overall straw yields are significantly greater in Barry Sine. But legume hay yields are smaller there (Table 2).

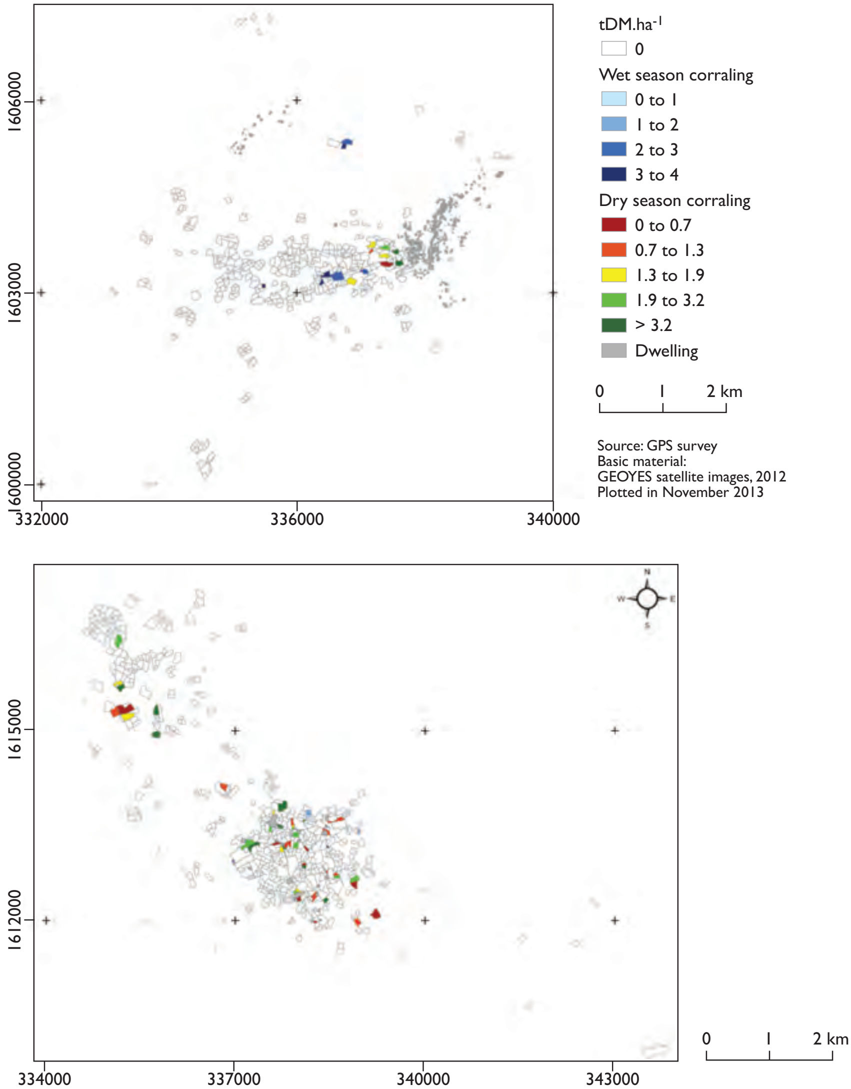

Figure 6.

Figure 6. Location of night corralling in the rainy season and the dry season in Diohine (top) and Barry Sine (bottom) in 2012.

The fate of the by-products also varies from one *terroir* to the other because of their different livestock systems. The free-ranging livestock system is dominant in Diohine. This implies that sufficient quantities are left in the field to allow free-ranging. In contrast, fattening is carried out in Barry Sine and this means that the locals gather the greater part of the by-products (Table 2).

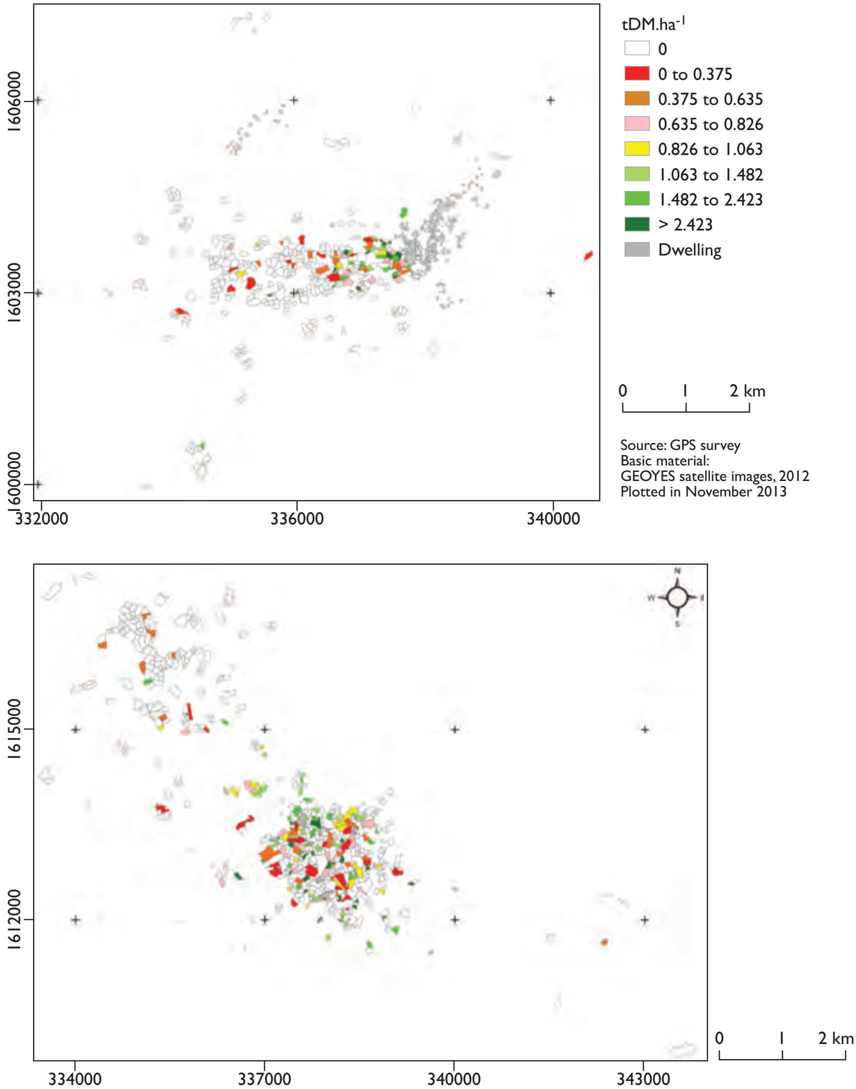

Figure 7.
Manuring intensity in Diohine (top) and Barry Sine (bottom) in 2012.

Sustainability indicators

At field level

Barry Sine uses significantly more inputs per hectare at the field level than Diohine (13.5 $kgN.ha^{-1}$ in Diohine; 23.5 $kgN.ha^{-1}$ in Barry Sine). In contrast, the gain in production (+15 $kgN.ha^{-1}$) is not compensated by the gain in inputs (+10 $kgN.ha^{-1}$). Indeed, fodder exports—especially for feed for fattening—are greater in Barry Sine.

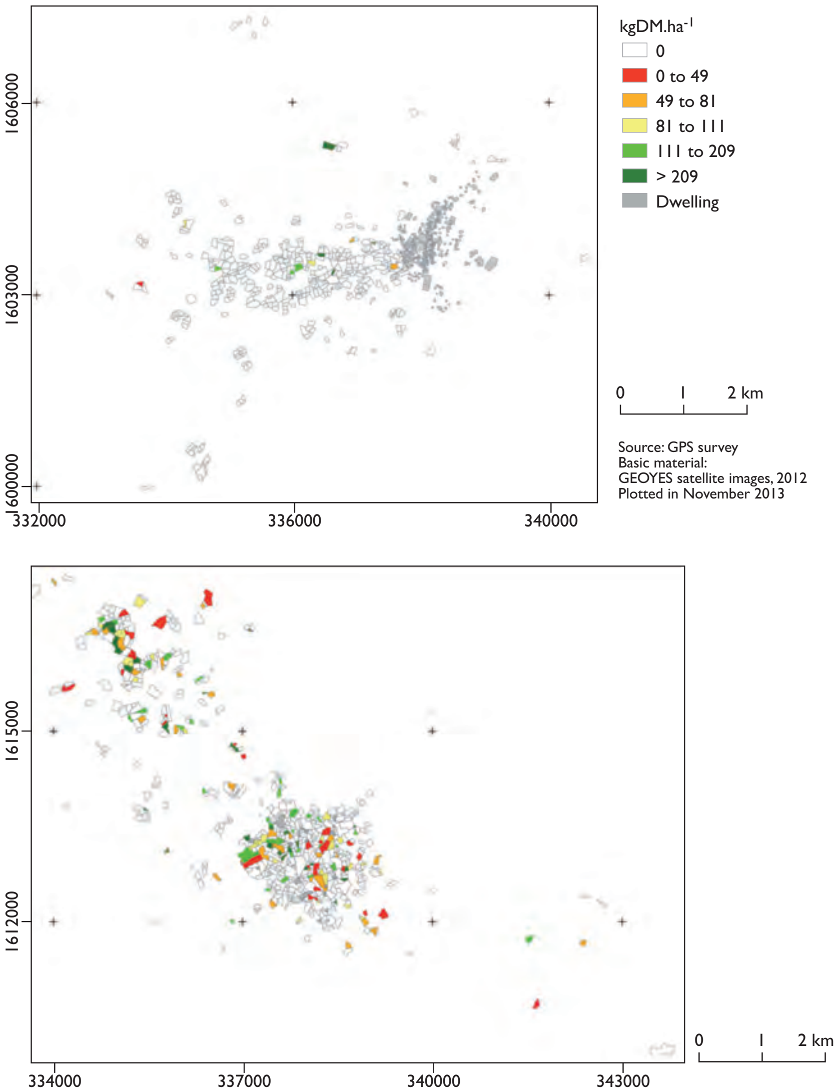

Figure 8.

Figure 8. Intensity of the spreading of mineral fertilisers in Diohine (top) and Barry Sine (bottom) in 2012.

Finally, farming practices have little effect on the nitrogen balances of the two villages, whose averages and medians do not have a significant difference (averages of -20 kgN.ha^{-1} for Diohine; -23 kgN.ha^{-1} for Barry Sine) (Fig. 9).

Comparison of the spatial distribution of field nitrogen balances and after an ANOVA test, Diohine converges towards the traditional model with higher N balances in compound fields than in bush fields. In Barry Sine, this difference in N balance with remoteness from the dwelling is not significant.

Table 2.
Comparison of the yields of the main crops and the proportion of by-products left in the fields in Diohine and Barry Sine in 2012.

	Main products (ear/pods)			By-products (straw/hay)					
	Yield (kgDM .ha^{-1})						Proportion of by-products left in the field (%)		
	Millet	Sorghum	Groundnut	Millet	Sorghum	Groundnut	Millet	Sorghum	Groundnut
Diohine	626	480	371	1823	1067	1171	60	44	31
Barry Sine	727	779	366	2418	2505	696	43	13	0

(in red, the lowest figure for a variable compared with the other village; in green, the highest figure for the variable compared with the other village.

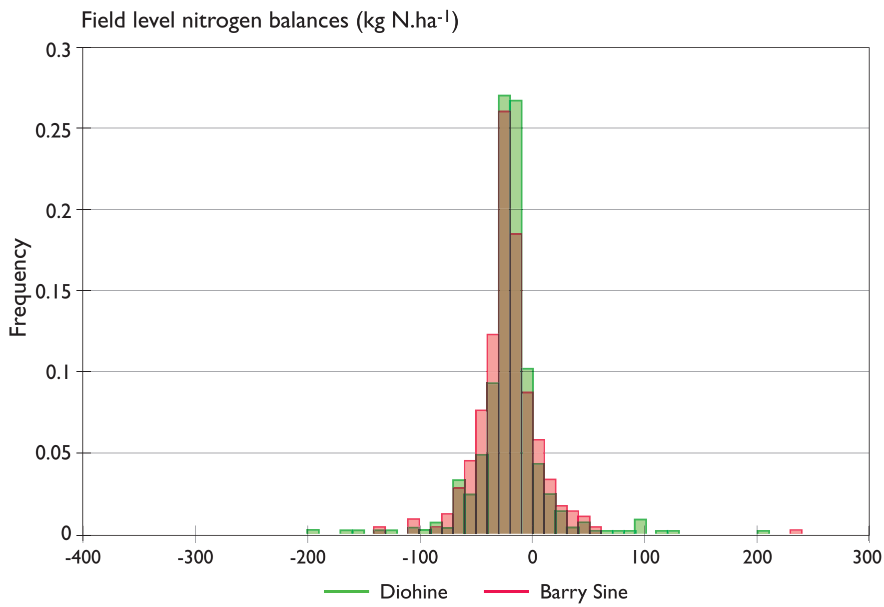

Figure 9.
Graph of the distribution of nitrogen balances by frequency in Diohine and Barry Sine in 2012.

Heterogeneity is also greater in Diohine, probably because of the markedly different management practices used in compound fields and bush fields.

At household level

Farming practices in Barry Sine are resulting in increased use of inputs such as mineral fertiliser, concentrate feeds and foodstuffs (incoming N flows: 3 kg N.inhabitant^{-1} in Diohine; 20 kgN.inhabitant^{-1} in Barry Sine) while production in Diohine is based essentially on the use of local resources with the recycling of biomass from livestock farming, crops and trees. This surplus of inputs is devoted essentially to fattening as purchases of foodstuff are similar in the two villages (1.62 and 1.66 kg N.inhabitant^{-1} in Diohine and Barry Sine respectively).

Analysis in greater depth of the nitrogen flows at household level shows that the trend in Diohine is more towards on-farm consumption while in Barry Sine the focus is on the sale of farm production. Indeed, sales of plant and animal products are much higher in Barry Sine (1 kg N.inhabitantt^{-1} in Diohine; 13 kg N.inhabitant^{-1} in Barry Sine).

The flows resulting from the movement of free-ranging livestock are dominant in Diohine, whereas inflows and outflows related to fattening are dominant in Barry Sine. These figures show the importance of livestock farming in the functioning of the two *terroirs*, even though the livestock systems differ strongly.

The current practices and functioning of households result in N balances at this level that are greater on average in Barry Sine (13 kgN.ha^{-1} in Diohine; 24 kg N.ha^{-1} in Barry Sine). These nitrogen balances increase when the focus of the household is more on livestock. Indeed, ‘Subsistence farmers’ and ‘Fatteners’ have respectively the lowest and highest nitrogen balances at household level.

At *terroir* level

The results at *terroir* level are similar to those observed at household level. The nitrogen balances are positive in both cases and the balance is higher in Barry Sine (+8.5 kg N.ha^{-1} in Diohine; +24.9 kg N.ha^{-1} in Barry). The intensity of nitrogen flows is much higher in Barry Sine. Indeed, incoming flows are 7 times greater in Barry Sine (9.3 kg N.ha^{-1} in Diohine; 67.9 kg N.ha^{-1} in Barry Sine). Likewise, outgoing N flows are 35 times as high in Barry Sine (1.2 kg N.ha^{-1} in Diohine; 43.9 kg N.ha^{-1} in Barry Sine). These differences functioning result in N utilisation efficiency that is 4 times greater in Barry Sine than in Diohine (0.15 in Diohine; 0.64 in Barry Sine).

General discussion: the effects of fattening on the sustainability of *terroirs* in West Africa

Soil impoverishment is a problem common to numerous countries in West Africa (Smaling *et al.*, 1997). It is seen in Figure 10 that West African nitrogen balances are generally negative at the field level. Even though methodology may differ from one study to another, the balances for Diohine and Barry Sine are comparable with those for the sub-region (Schlecht and Hiernaux, 2004).

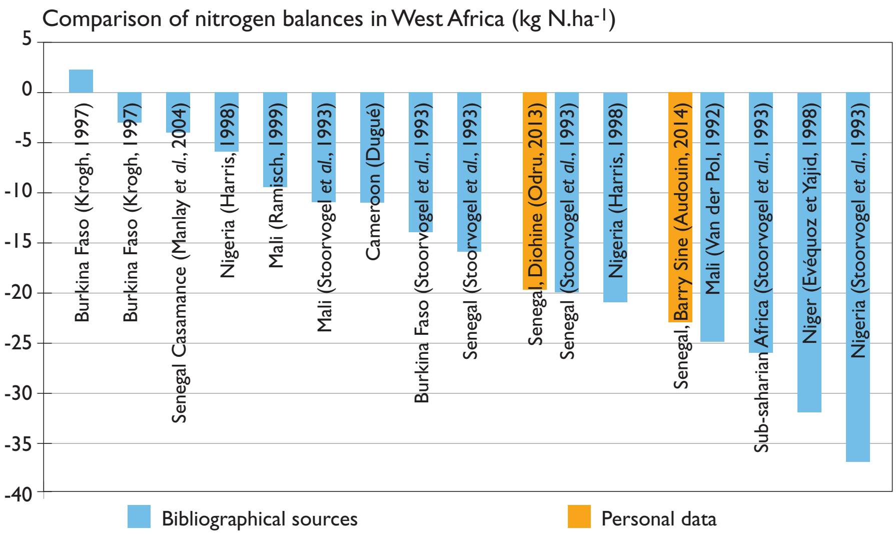

Figure 10.
Nitrogen balances at the field level in West Africa.

This study of biomass and nitrogen flows describes the case of Diohine, confirming that the presence of livestock strongly calls into question the traditional system based on the close complementarity between livestock farming, crop farming and trees (LERICOLLAIS, 1999). Indeed the fertility transfers traditionally governed by free-ranging ruminants (MANLAY *et al*, 2004) are becoming insufficient to make up for N outflow via crops, whence the negative N balances at field level and slightly positive N balances at the household and *terroir* level in the case of Diohine (Table 3).

This study shows that the farming system based on fattening allows an increase in the number of head of ruminants at *terroir* level. The livestock stocking rate is higher in Barry Sine and the animals are better fed (see above). This results in the availability of more manure and a larger supply of organic matter at the field level in Barry Sine (+2.2 kg $N.ha^{-1}$). As a result, the yields of millet—the main crop in both *terroirs*—have increased on average. This gain in yields corresponds to a surplus of +101 kg $DM.ha^{-1}$ of ears and +595 kg $DM.ha^{-1}$ of millet straw (see above). These gains in average yields at the level of the *terroir* make it possible to feed more head of livestock and contribute to increasing meat production by 189 kg $LW.ha^{-1}$, the sale of which is a useful cash return for purchasing mineral fertiliser and foodstuff. Fattening thus intensifies crop production indirectly and supports a population density 78% higher (see above), thus confirming the hypothesis of DUNCAN *et al.* (2013).

In order to maintain a high stocking rate (2.31 $UBT.ha^{-1}$), Barry Sine farmers as a whole import an annual 411 t DW of concentrated feeds (see above). The use of imported concentrated feeds is a debatable point. It is true that it reduces the autonomy of households and exposes them to fluctuation of prices of cereals and

Table 3.
Multi-level comparison of the sustainability indicators of the villages.

		Diohine	Barry Sine
Nitrogen balance (kg N.ha^{-1})	Field	-19,8	-23,0
	Household	12,7	25,1
	Terroir	8,5	24,9
Nitrogen efficiency (Dmnl)	Field	12,5	3,84
	Household	0,78	0,89
	Terroir	0,15	0,64

processing by-products, but it also reduces the pressure of farming systems on local natural resources and makes them less sensitive to climatic variations. Indeed, in the traditional system (like that in Diohine), great demand is made on trees in dry years to make up for the shortage of crop residues needed to feed livestock. But the sustainability of such a system is called into question strongly during prolonged drought like that of the period 1970-1995. With a system centred on fattening (such as that at Barry Sine), the shortage of fodder in dry years is felt less because most of the ration consists of concentrated feeds.

Table 3 shows the great difference between results at field level and those calculated for the household and the *terroir*. Indeed, the nitrogen balance is negative at field level and amply positive at the higher levels. Analysis of N flows in greater depth accounts for these differences in the N balance, showing that a proportion of available organic matter (manure, faeces and urine) is not used in cultivated fields. Thus part of the nitrogen accumulates at the dwelling level in both villages. The difference between the N balances is even greater for Barry Sine (see above) where manure is even less well used. Analysis of N flows by household shows that the use of manure depends considerably on the type of household (see above). As a general rule, the

Table 4.
The environmental, technical and economic benefits of the installation of manure pits. Per household and per year (AUDOUIN, 2014).

Type of households	Number of 9 m^3 pits required	Manure (kg DW.ha^{-1})	Millet grain (kg DW .ha^{-1})	Return (€)	Field nitrogen balance (kg N.ha^{-1})
1- Newly installed	2	+155	+21	+30	+3.1
2- Subsistence farmers	2	+58	+9	+17	+1.9
2'- Cash crop farmers	5	+231	+34	+45	+5.8
3- Traditional mixed farmers	2	+20	+6	+8	+2.4
3'- Fatteners	8	+357	+142	+327	+4.3
Average sur Diohine	2	+24	+3	+1	+1.8
Average sur Barry	4	+161	+30	+64	+3.3

more manure available, the less will be spread per TLU. Indeed, certain households ('Fatteners') concentrate only on the sale of livestock, pay less attention to crops and import a large proportion of the feed using the proceeds of fattening. In contrast, households that focus on both the sale of fattened livestock and a cash crop ('Cash crop farmers') make better use of manure. This has also been noted in other contexts of the development of sales-orientated livestock farming in sub-Saharan Africa (Rufino *et al.*, 2009; Schlecht *et al.*, 2006).

Audouin (2014) evaluated for the two villages the environmental, technical and economic advantages of making better use of manure by installing manure pits, assuming that haulage equipment and labour would not be limiting factors (Table 4). Manure pits mean an increase in the biomass collected (rough stems that would otherwise be burned) and a reduction of losses of gaseous N (Blanchard *et al.*, 2011).

The analysis shows that the gain would be particularly substantial in the *terroirs* in which fattening is preponderant, as in Barry Sine (Table 4). The advantage is much smaller for households with small livestock stocking rates and where the dominant livestock system is the free-ranging type as in Diohine. Indeed, manure production is limited there.

Conclusion

This study provides a comparative view of two village *terroirs* that have followed different pathways in order to adapt to the changes in their environment. Diohine, the first, is close to the traditional Sereer agro-sylvo-pastoral system organised around fallow and free-ranging livestock and is strongly dependent on trees during the lean period. The second, Barry Sine, is managed more intensively and centred on stabled fattening. Farming practices and the resulting biomass flows were described by means of surveys and used to calculate indicators describing the productivity of the *terroirs* and the evolution of soil fertility.

Diohine is an old *terroir* in which the inter-generation social hierarchy is still strong. The weight of tradition has contributed to maintaining the collective management of resources by organising a common fallow that enhances interaction between households via free-ranging livestock. The ownership of livestock is strongly linked to social status and determinant for agricultural productivity and the maintaining of soil fertility as most household nitrogen input is based on common grazing and night corralling practices.

The Barry Sine *terroir* is more recent. It has developed into a more individual and more intensive resource management system as most household nitrogen input is based on the importing of concentrated feed for fattening. The village has also conserved commercial groundnut growing, facilitated by mineral fertiliser spreading 5.7 times as high as in Diohine (in terms of nitrogen). Its agricultural equipment allows better distribution of nitrogen application between compound fields and bush fields. The Barry Sine *terroir* is thus more productive because of an increase in crop yields (+39% N for main products, +45% N for by-products) and livestock productivity (x 9 kg $N.ha^{-1}$ produced as meat).

Analysis of biomass flows shows that livestock still plays a major role in the organisation of the nitrogen cycle in both villages. In Barry Sine, fattening increases the presence of ruminants in the village *terroir* and field input of nitrogen in the form of manure thus increases by 1.5. However, the nitrogen balances at field level remain negative in both *terroirs* (-20 kg $N.ha^{-1}$ in Diohine; -23 kg $N.ha^{-1}$ in Barry Sine). They reveal insufficiently sustainable management of soil fertility explained by the amount of outgoing flows from the fields and the limited return flows. The present farming systems are thus based on non-sustainable drawing on soil resources. Margins for progress are nonetheless possible as the nitrogen balances of the *terroirs* (+9 kg $N.ha^{-1}$ in Diohine; +25 kg $N.ha^{-1}$ in Barry Sine) and households (+13 kg $N.ha^{-1}$ in Diohine; +25 kg $N.ha^{-1}$ in Barry Sine) are positive. The differences between the balances show that nitrogen accumulates at dwelling level and that nitrogen recycling is not optimum. This results in particular from the less than optimum use of manure.

The populations of the two *terroirs* are aware of the decrease in soil fertility and show particular interest in the intensification of farming systems by the application of animal manure. They are thinking in particular of increasing manure use by installing manure pits. This would be beneficial from the environmental point of view (better N balances at the field level). The advantages of this innovation are clearer for Barry Sine from the technical and economic point of view as fattening operations generate substantial quantities of manure.

In a context of climate change and strong demographic growth, this question of intensification options for village farming *terroirs* is common to many parts of West Africa. Intensification by the introduction of livestock fattening seems to be a promising pathway. The option not only has the advantage of increasing livestock and crop productivity but also improves household finances and reduces their sensitivity to local climatic variations as feeding livestock is less dependent on the fodder availability, thus reducing pressure on local resources, including tree layer during droughts.

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Chapter 20

An example of adaptative strategy in the face of food insecurity
Potato growing in the Imanan (Niger-republic)

Ramatou HASSANE

Introduction

The practice of growing potatoes is of major interest for the local populations. In the Imanan's local government area, the yielding of the potato constitutes both a response to the food crisis due to climate changes, environmental instability, demographic increasing throughout the zone and the economic crisis that the country has overcome since 1980s. It is also a driven response due to a high increasing demand in fresh products (fruits and vegetables) of Niamey's metropolis. Although the returns contribute significantly to farmers' food requirements, the procedure for funding the crop puts them in a secondary position in relation to those who sell the crop on the market. For lack of financial resources, farmers have to sell their products to traders on a working-class market in Niamey—referred to as 'the little market'. The traders supply farmers with seed and inputs on credit.

The aim of this chapter is therefore to illustrate that potato farming contributes to improving the well-being of the population in the rural area of the Imanan and to analyse the determinants of the funding of this yielding.

Methodological procedure

The choice of the local government area of Imanan is justified by the scale of single cropping of potatoes, the economic contribution of the crop and the diversity of farmers' situations. Data were collected over a period of seven months (September to/and October 2011 and December 2012 to April 2013) in fourteen villages using a diagnostic survey, direct observations of crop management sequences, the supply of planting material and the sale of the potato crop. The approach was based on interviews with male and female farmers, development agents, elected officials and traders. A questionnaire completed by one hundred and twenty market-gardeners was processed using the Excel program to assemble quantitative data. The basic data are completed by bibliographical analysis.

Context of the study

Imanan is a local government area [district] in the Filingué department in the Tillabéri region in south-west Niger. With a land escape of 506 square km, it is centred on part of the Dallol Bosso fossil valley in a narrow section not more than 5 km wide before it broadens again towards the north. It is bordered to the east and the west by sandy argillite plateaux. The population was estimated in 2011 at 36,767 persons (PDC, Imanan, 2012), made up of several ethnic groups: Touaregs, Haussa, Zarma, Peuls and Kanuri. The people live mainly on crop and livestock farming which is more subjected to both physical and anthropic pressures.

Worsening of the climate, a limit to rainfed agriculture

Imanan has a Sahelian climate featuring precipitation that is small and irregular in time and space. According to Larwanou *et al.* (2005), the Filingué department is one of the arid zones of the Tillabéri region, with a bioclimatic aridity index of 0.17 to 0.15. Aridity takes the form of a permanent rainfall deficit. It is related to other climatic phenomena such as strong insolation, high temperatures, low relative humidity and strong evapo-transpiration. Average annual precipitation in Imanan from 2006 to 2012 was 430.5 mm, with precipitations occurring during three to four months (June to September), conditioning the annual production cycle for crop and livestock farmers. Aridity has caused the disappearance of certain temporary and permanent ponds, and the forming of several ponds, especially on the plateaux. The ponds have encroached on fields in the village of Tassi Sofo Koira on the western plateau. The local population says that the groundwater level has also fallen.

'The bush has disappeared, with almost all the trees': this phrase that came up frequently in discussions with farmers refers to an accelerated decrease in vegetation, and even the disappearance of certain shrub and herbaceous groups. The worsening of the climate has been at the expense of plant cover, which is either replaced by traditional crops or over-exploited by graziers. On the subject of the valley of Imanan, Guillaume (1974) wrote that its rich pasture and flora, the presence of ponds and the shallow depth of the wells and the abundant fauna were all features to be considered in understanding the region as an area for the settlement of groups of migrant nomads

(Peuls, Tuaregs and Bella) and the form their settlement had taken from pre-colonial times onwards. However, less than a century after their settlement, the rapid ecological deterioration of the local environment is considerable. The agricultural activities of the local populations have greatly suffered from the increase in aridity.

Indeed, before the major drought of 1973 and 1974, rainfed farming met the requirements of the population. The latter was small at that time (12,185 habitants in 1975) and there was still sufficient livestock in the district of Imanan. Milk and the millet and cowpea harvests provided for the basic requirements of farms. The seasons were regular and rainfall abundant. Household food vulnerability started to emerge during the 1973 famine as a result of drought and agricultural policies that favoured the development of cash crops. It worsened after the 1984 drought. Since then, Imanan has experienced a succession of famines and food crises (1993, 1999, 2001, 2005, 2010 and 2011). The years of shortages, the small number of days of rain (only 34 in 2012) and the very local nature of precipitations limit the development of crops and pasture. Fields that used to give more than 300 bundles of millet yield hardly more than 20 to 80, on the one hand because rainfall has decreased and is irregular and on the other as a result of soil degradation. Granaries are empty hardly a month after the harvest and at best ensure the survival of households for a few months. Many farmers thus suffer from a vulnerable situation as regards food or even from food insecurity.

Food vulnerability means the probability that the food security of a household will be threatened by a climatic, social or economic shock. It is also ‘the inability of a person to anticipate, face up to, resist and recover after the impact of an event’ (Bidou and Droy, 2007). Vulnerability affects the behaviour of persons (in terms of investment, protection patterns and adaptation strategies) and their perception of their own situation (Balla *et al.,* 2009). Food insecurity refers to a situation in which the population does not have access to healthy, nutritive foodstuffs in sufficient quantities to cover food requirements. When this results from much more occasional and short-lived risk factors (droughts, floods, invasion by acridians, epidemics) it is considered to be conjunctural. It is described as chronic when the state of structural poverty of persons living in an unfavourable environment means that they do not have access to resources to cover their basic food requirements (Alpha Gado, 2010).

There are no consumer surveys enabling the precise determination of the real movements in Imanan. The only data we have are those for the entire Filingué department (Fig. 1).

It is shown in Figure 1 that requirements increase steadily at the rate of demographic growth whereas production increases unevenly, with years of surpluses alternating with years of deficits. The cereal balance[1] shows that surpluses have tended to disappear during the run-up to the present period. There is a deficit nearly one year in three. While traditional cereals are still dominant, farmers observe a general trend for degradation of the food balance situation. With the degradation of their

1. The cereal balance is the difference between net production (production during the year of reference + stocks) and the requirements of local people (rural sedentary, nomad and urban).

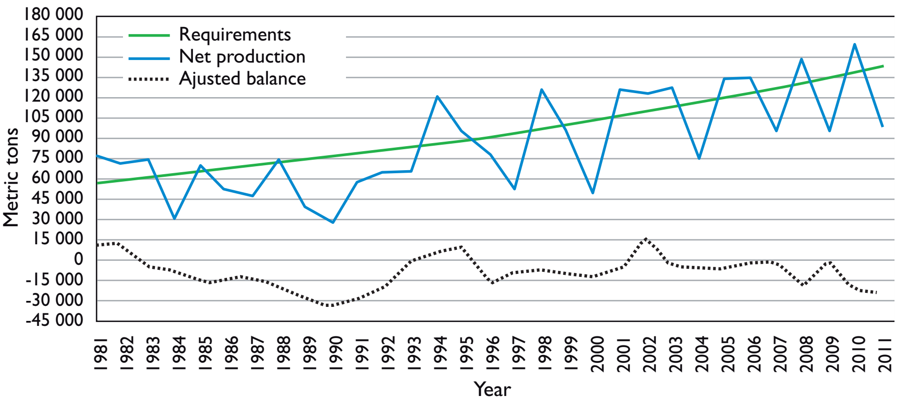

Figure 1.
Cereal balance in the Filingué department from 1981 to 2011.

environment and worsening living conditions, they have developed subsistence strategies to adapt to the variability and singular nature of the situations experienced. Their abilities result in continuous change in the way potential resources are allocated and used.

Potato yielding as a dominant adaptive strategy

The subsistence strategies of rural households concern mainly the sale of livestock, market garden crops, small trading, agricultural wages, and the use of solidarity networks and/or the migration of a family member (DRAMA YAYÉ and ALPHA GADO, 2005). However, the features of these strategies depend on the severity of crises and on geographical location and also on gender, social status and the degree of vulnerability of the household (ibid.). Households do not therefore use the same strategies systematically. Furthermore, distinction should be made between old and new subsistence strategies.

In Imanan, farmers' food strategies were founded mainly on a search for more fertile land. They involved the clearing of new land and the exodus from Touareg concessions to the small valleys cut in the plateaux. Farming land on the plateaux had made it possible to leave fallow certain fields of the Dallol and this enhanced their regeneration at first. But the Touaregs' desire for this land caused the shifting of the Zarma from Tondikandia, the neighbouring canton, to their plateau land to prevent it from finishing in the hands of the Touaregs. Some Tuaregs or Bella farmers who had cleared the land returned to the Dallol to maintain possession.

In order to profit from animal and human faeces during the rainy season, farmers whose fields were not close the villages took their families to settle on the remote fields that belonged to them. This resulted in small compact hamlets called *tiseged* at the junction between several fields or sometimes on the land of one farmer. However, the *tiseged* became permanent because of the increasing sterility of Dallol soils and strong landholding pressure. Farmers settled on their land in an isolated manner to enrich the soil. This was first the case of poor Bella who had no livestock and wanted to manure their fields with their own faeces. The dispersion of the population resulted in the decline and sometimes the disappearance of the large villages. However, those who left maintained links with their native villages. They continued to maintain their abandoned concessions and paid taxes to the chiefs of their former villages. New norms then emerged that affected the population's representation of the spatio-temporal concept of 'village'.

The hiring out of labour and the migration of one of more members of the household are longstanding phenomena in Imanan. There are two forms of work for other farmers: in the first case this is individual paid labour and in the second it is aimed at being collective and generally organised by rich heads of concessions, but with daily payment in kind or cash. Migration is an old tradition for good workers in the district. Distinction is made between migration of indeterminate duration and seasonal migration. The former does not seem to be very common today. It was strongly determinant before the decree of 1946 that forbade obligatory labour and consisted of massive departures for the British colonies in order to escape the constraints of forced labour in the French colonies. Seasonal migration is a regular and habitual phenomenon in the economic cycle of a large proportion of the population. The amplitude of this temporary exodus varies according to the quality of recent harvests. Some migrants who have slender resources and are not yet adult leave for other towns in Niger. The others prefer countries in the sub-region (Benin, Togo, Côte d'Ivoire, Ghana, Libya, etc.) where they do small jobs in return for pay, a large proportion of which is for looking after the family members who stayed at home. Migration has also concerned women for a number of years. On their return, those who go to the capital are considered to be more sophisticated because they have more resources and experience than those who have always stayed in their village.

The use of new economic activities is representative of more recent strategies. These are the means used by most of the population to compensate for the inadequacy of agricultural production to cover minimum requirements. Distinction is made among other things between crafts, trade and paid work. Other smaller trades are practiced such as the sale of manure, wood, straw, etc. But the largest activity is market garden farming and mainly potato growing.

This type of farming used to be a marginal agricultural activity. Counter-season crops were grown in compound gardens by women only. The small yields were just a complement within the framework of traditional subsistence farming. The only crop that developed was tobacco after the rise in price of that from Nigeria in 1898. It was grown by the women and sold by the men. Tobacco growing disappeared during the famine that hit the region in the 1950s even though competition with tobacco growers in the Ader had continued. Little importance was awarded to counter-season crops at the time. Their weak development was the result of ignorance as regards cultural techniques, input prices that were too high, the rigidity of land tenure structures and lack of confidence in the instructions of distant agricultural counsellors and supervisors (GUILLAUME, 1974). It was also related to the lack of outlets. Only a few concessions of well-off families had continued to maintain gardens or vegetable gardens, including that of the head of the canton at that time.

A new type of garden has appeared in recent years: farms that are well-maintained during the dry season and where market garden crops are grown, marking a change in comparison with subsistence farming (millet, sorghum, cowpea, groundnut, etc.). Uncertain waiting for rainfall is replaced by irrigation and yields are increased by fertiliser application. While other crops are for on-farm consumption, potato is a cash crop.

The Tuaregs of Imanan discovered the ‘patata’ of the Incas in 1954. A young market gardener was given a few potatoes in 1954 by a Frenchman called Bernard who was supervising the building of a road from Niamey to Filingué. A member of a family of immigrants from the eastern part of Niger (Diffa), the farmer had started market gardening operations in 1952. The idea of market gardening had occurred to him when he had migrated to Côte d’Ivoire. He reports that farmers laughed at him and thought that he was mad. A song was composed for him, ‘*pompi may bada roua*’—which means ‘the pump that gives water’, to make the distinction between irrigation and rain. Potato growing spread slowly during the first three decades after the crop was introduced in Imanan. Today, the crop has a prime position in farming traditions in the Bonkoukou geographic sector. It is fully part of local farming systems and accounts for 87.91% of the total area of 139.18 hectares devoted to counter-season crops in 2012.

Initially aimed at providing complementary income for a few farmers, potato growing has now become a permanent adaptive strategy. Several factors have favoured its spread and development.

Factors involved in the diffusion of potato growing

Diffusion covers all the processes that contribute to movement, to migration in geographic space and the effects that these movements give in return (SAINT-JULIEN, 1985). The dynamics of potato growing has been generated by individual and collective stakeholders, local events and events outside the administrative district.

Internal factors

Factors associated with local evolution and events concern demographic growth, the existence of lines of communication and the role played by local stakeholders.

Indeed, pressure on land resources is preponderant in an environment subjected to strong demographic growth.

> ‘Much-divided areas of farm land, of the size of a ‘kurga’ or field are no longer enough to feed an increasing number of people’ (interview of an old potato grower, Inatess, 13 January 2013).

When extension is no longer possible because there is hardly any new cultivable land, the intensification of farming systems always outweighs extensification. Farmers can draw income from market garden crops especially as groundwater is at a shallow depth—2 to 5 metres—making it easier to obtain water for irrigation.

Local stakeholders have established a network of potato growers by setting up the Bonkoukou market garden crop cooperative. It was started in 1998 by a person from the district. The cooperative works on searching for partners, strengthening the capacities of its members, technical support in agricultural equipment and supplying the district with certified seed potatoes. It built a storage warehouse to improve keeping quality. The warehouse was to be the collection and storage point to stagger potato sales using the warrantage principle[2]. However, management problems (the managers of the cooperative used aid from partners for their own profit) mean that most growers do not use the system. In spite of these problems, new groups of potato growers have formed and so farmers can organise themselves better and those involved to can coordinate their actions better.

External factors

External factors are economic, social and political. They consist in particular of intervention by development projects, access for growers to new IT technologies and to the market.

Development project actions are focused on technical and financial support for farmers. Projects have developed collective market garden sites to provide land for certain farmers-especially women. They have dug individual wells on the farms of many growers. Thanks to them, most growers have discovered certified planting material imported from Europe and much sought after as its yields are higher.

Use of motor pumps is certainly the water lifting method that has had the most effect on potato growing methods. The motor pump is connected to a drilled well or a modern dug well—that is to say a cement well. During the first decades of potato growing in Imanan water was carried out by hand from sumps. A bucket-like container was used to raise water. From 2000 motorised pumps were definitely adopted in Bonkoukou. Use of these then spread to the other villages. Drilled wells were introduced in the zone by well drillers from eastern Niger. They cost CFAF30, 000 to 45,000 according to the depth of the groundwater and the diameter of the tubes used. These two new methods encourage farming on a larger scale and the use of temporary and permanent farm labour increased.

2. Warrantage is a loan operation lasting for a few months in which the collateral is a stock of foodstuff that can be sold by the bank or microfinance institution in case of default.

Linked to Bonkoukou by 145 km of metalled road (the Filingué road), the capital, Niamey, has played a twin role in the increase in potato production. It is both the centre of supply and consumption. As a supply venue, the 'small market'[3] in Niamey is the main supplier of seed potatoes to Imanan growers. Since the first production of potatoes, the major part of supply of inputs for growers has been handled by wholesalers, referred to as '*Maï Gida*'[4], via the small market in Niamey. Niamey is a consumption centre, forming a reliable outlet for growers. As soon as it has been lifted, practically the entire crop is sold on the markets of the capital during a period of no longer than 3 months. Potatoes were long considered as a luxury vegetable that only wealthy people could buy because of their high price but consumption has now increased. It is increasingly part of the range of produce bought by urban consumers. The change doubtless results from the change in the eating habits of town-dwellers and the demographic growth of Niamey.

However, technology that has been a success in one place will not necessarily succeed elsewhere. If the farmers in a region grow a certain crop then they consider it to be 'profitable' with regard to their needs and the resources and production facilities to which they have access (FERRATON and TOUZARD, 2009). The farmers have chosen potato from among all market garden crops because it is the most efficient. The average yield is 32 metric tons per hectare. As it has a short cycle—'three months at most'— it frees both land and labour from February onwards. It does not compete with traditional crops and is a profitable crop in terms of cash returns. Potatoes sell rapidly in Niamey at increasing prices (less than CFAF75 in 1980-1990 and now CFAF300 today). Potato production optimises farmers' cash incomes and enables them to overcome food insecurity.

The improvement of the well-being of the population in the potato's farming

In cases of food insecurity, farmers' cereal grain stocks are insufficient or lacking and a rise in price is followed by falling livestock prices. The major difficulty for households is then to accumulate sufficient stocks to cover their food requirements during the lean period. It is essential to be able to find cash to purchase the cereals required for the survival of the family unit. Potato growing is a palliative for climatic and fertility crises and contributes in different degrees to the subsistence and lives of households. Its economic impact is expressed in terms of on-farm consumption and opportunities for work and income.

3. The '*petit marché*' (small market) or *Habou Ganda* is right in the centre of the capital, Niamey. It is the main vegetable market.

4. *Maï Gida* means 'head of the family' or 'head of the household' in Hausa and, by extension, 'employer'.

Potato is a vegetable with high nutritional value. According to VANDENPUT (1981), it is the plant that 'produces the largest amount of food per day of occupation of land'. Whereas the first growers did not even know how to cook potatoes and grilled them above embers or cooked them in hot ash, forms of local consumption are now very varied. Potatoes are cooked as ragout or chips. They are also served with sauces. The leaves are picked fresh several days before the harvest and dried and cooked; they are used in couscous or *dambu*. The rest of the plant is used as animal feed.

However, the proportion used for on-farm consumption is small. It accounts for only 4% of total production (Fig. 2).

Small tubers called *meno* in the local language are those mainly concerned. When they sell their crop, growers always sort the potatoes. The large ones sell fast at a good price but it is difficult to find takers for small ones and these are sold at a very low price.

Market gardeners generally have two or three beds of other vegetable crops, practically entirely for on-farm consumption. Growing potatoes gives farmers access to other vegetables (onions, lettuces, cabbages, tomatoes, peppers, etc.). This reduces their expenditure on vegetables, increasing their cash reserves. They break with their eating habits and eat a variety of vegetables for a certain time like, as they say, 'Niamey people'.

Market gardening is also a competitive activity that opens up a new type of employment prospects for a fair number of persons who face unemployment. Practiced in towns, it helps many people to overcome their food problems and to improve their living conditions. There are full-time or part-time jobs for the various categories of person involved (MUKADI and TOLLENS, 2001). There is no work for farmers during the dry season in Imanan. Rural labour operates for hardly more than 3 or 4 months a year—that is to say during the rainy season crops. Working during the dry season gives farmers something to do while earning extra income. Potato needs paid labour—more than traditional crops. Monthly wages vary from CFAF12, 500 if the worker is housed and fed to CFA 20,000. The use of paid labour enables young people and those with limited resources to earn enough to live during the three months of the potato production cycle.

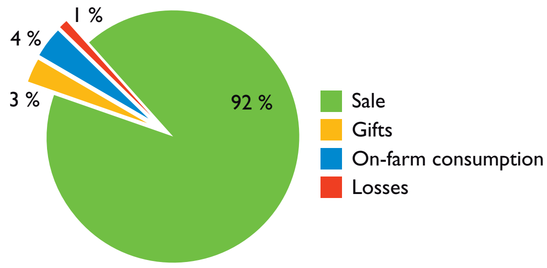

Figure 2.
Distribution of potato production.

One of the parameters of food security is the financial ability of households to obtain foodstuffs, whence the advantage of having at least some income. In Niger, the National survey of household budgets and consumption (*Enquête nationale sur le budget et la consommation des ménages*) performed in 2007-2008 by the Institut national de la statistique (INS) set the poverty threshold[5] in 2008 at CFAF150,933 in urban areas and CFAF110,348 in rural areas. Operating accounts for potato calculated using the evaluation method described by FERRATON and TOUZARD (2009) show that, on average, farms where water is lifted manually and that do not use external labour generate a net margin of CFAF 229,290.36. The figure is CFAF467, 318.83 for farms with motorised irrigation and that use paid labour.

The results shown in Table 1 show that potato growing earns income for farmers that is well above certain thresholds. Indeed, when they have sold their crop, more than 70% of the farmers show gross returns of more than CFAF200,000 and the figure is more than CFAF500,000 for 30% of all growers. The returns depend on the farming system used. The more this is motorised, the more a farmer can invest in the crop and increase his profits.

The income earned is used first to pay debts incurred within the framework of production. It is then invested in the purchase of cereal grains with priority going to millet, maize, rice and sorghum. It appears that 85.47% of the farmers surveyed buy

Table 1.
Operating account for potato with and without motorised pumping.

Type of farm		**Manual irrigation**	**Motorised irrigation**
Seed potatoes (kg)	*58.33*	*151.33*	
Operating costs	Seed	46 035.71	118 968.49
	Fuel	0.00	51 654.11
	Engine oil	0.00	3 539.73
	Manure	285.71	1 222.60
	Fertiliser	1 216.67	1 884.25
	Pesticides	104.88	345.07
Intermediate consumption		**47 642.97**	**177 614.25**
Total production	Production sold	254 535.12	646 121.58
	Gifts	8 785.71	18 625.68
	On-farm consumption	10 601.79	20 058.90
	Storage losses	3 010.71	4 250.34
Gross yield		**276 933.33**	**689 056.51**
Gross value-added		**229 290.36**	**511 442.26**
Wage costs	Payroll	0.00	35 517.26
	Payroll costs	0.00	8 606.16
Cost of paid labour		**0.00**	**44 123.42**
Net margin		**229 290.36**	**467 318.83**

5. The poverty threshold is the level of the well-being indicator that shows if a household is poor (the indicator of well-being is below the threshold in this case) or not poor (if this is the case) (INS, 2009).

cereals. This enables them to store production placed in family granaries and use it as seed for rainy season crops. Once the family's cereal grain requirements have been met, heads of households invest in livestock. Purchase of livestock thus depends on the profit from production and the level of family consumption. Livestock can be sold throughout the year to meet requirements such as farmworkers' wages, health expenses for members of the household, the schooling of children or the purchase of seed for rainfed crops. Purchase of livestock mainly concerns small animals and income from potato growing contributes in a limited manner to the reconstitution of livestock numbers in the district. However, some farmers report that they had bought cattle thanks to the potato crop.

Income from potato is also spent on the purchase of means of transport (motorcycle, cart and bicycle). It is also used very frequently for expenditure on a marriage, a baptism, clothes, building a house, etc. The main aim of farmers is often to marry for the first, second or third time or to organise the marriage of a close relation. Numerous marriages are scheduled at the end of the irrigated crop season and especially in February and March, whereas they used to be held at the end of the rainy season. Likewise, having a house in adobe is an exterior sign of wealth. This requires more money than building a hut, the typical dwelling in the zone. A concession in adobe is for farmers today is the equivalent of what is represented by owning a cement house for a town-dweller.

Without the return from this resource, many farmers would have to sell part of the millet or cowpea to cover certain expenditure, whereas their harvests are too small to feed their families. Indeed, in the past the income from the sales of the cowpea crop was enough to cover the requirements of each household. Millet is not sold and cowpea financed expenditure on marriages, baptisms, clothes, etc. Even though cowpea sells better than the other crops, production has decreased considerably as a result of shortage of water and soil infertility. The income from potato is thus replacing that of cowpea.

The potato crop also affects the profitability of traditional crops. Several farmers report that when millet is grown in market garden areas the yield is higher than in the other parts of a field. This results from the application of organic fertiliser. The crop is also reversing the longstanding trend for young people to migrate to seek means of subsistence. More and more young people are more interested in growing potatoes than in migration. They establish their own farms by buying land if they have not inherited any or farm land that their parents or relations let them use. Remaining in the village, they participate in rainy season work either by providing labour or by covering part of the expenditure (labour, food, etc.) required. They are involved in the management of district affairs through the group that they have formed.

Income from potatoes also participates in the development of new economic activities. These include activities that bring in income (trade, fattening) handled in particular by women.

Thus, thanks to potato growing farmers ensure the food security of their households for a certain period of time. Rainy season harvests provide only three months of coverage of the cereal grain requirements of most farmers, of whom 65% grow

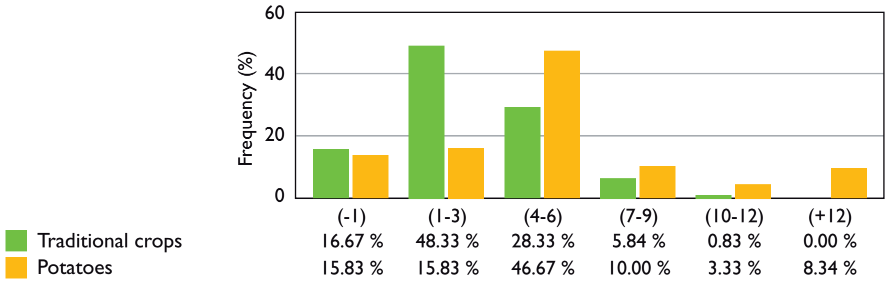

Figure 3.
The average duration of food stability conferred by the growing of potatoes and traditional seasonal crops.

potatoes. The returns from potatoes ensure food security for 68.34% of farmers for up to six months and for more than a year for 8.33%.

Whereas the administrator Taillandier wrote in 1953 that Imanan was characterised by a state of chronic shortage of food', the district suffered less from the 2005 famine. Its food vulnerability index is the lowest in the Filingué department after Tagazar district, with 34 and 37 points respectively in comparison with 52 for Kourfey, classified as 'extremely vulnerable' (Balla *et al.*, 2009). According to the local authorities, some villages have become self-sufficient and even show surpluses thanks to the potato crop. Thus, even the Kochilan sub-zone in the south of the district, which was more vulnerable because of division of land and the marked sterility of fields, is requesting less and less food aid.

Indeed, the coefficient of cereal-grain equivalence of potato is 0.228. If the 92% of the production sold by the 120 farmers surveyed were invested in the purchase of cereals, they would obtain 48.78 metric tons. Potato growing makes a 36.71% contribution to the family budget in comparison with 33.86% for traditional crops and 13.92% for livestock. The rest of the budget is covered by income from small trading, remittances from immigrants and other activities.

However, although potato growing in the rural district of Imanan is a way for farmers to break with monetary poverty and increase their resilience in the face of the food crisis, its funding is the subject of a fight for the upper hand between traders and growers.

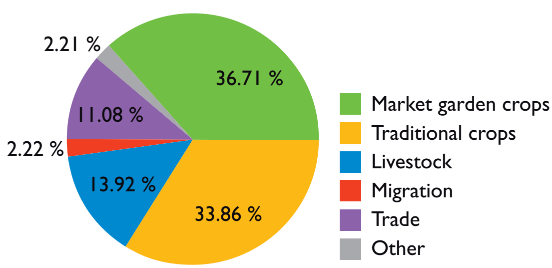

Figure 4.
The contribution of the main activities to farmers' family budgets.

The funding mechanisms of potato production

Distinction is made between two main funding procedures with reference to the different stakeholders: formal funding and informal funding. Subsidies, aid and gifts are part of the formal funding category. These form direct support for farmers from the public sector and development projects. It consists of inputs and farm equipment and services for farmers (training and technical assistance). Microloans are also awarded to solvent farmers.

Informal financing is seen at several levels. For some farmers, the funds used for the purchase of inputs come from the sale of livestock (sheep and goats). Those who have children outside the district or abroad may ask for aids. Farmers also rely on the generosity of members of their extended family (brothers, cousins, uncles, etc.) who work in particular in urban areas. Two or three farmers, that is to say 15% of our sample, pool their resources with the aim of sharing the profits. Farmers also award microloans amongst each other. The loan contracts are verbal and no interest is involved. Nevertheless, when the crop has been sold the borrower may give some potatoes to the lender or thank him by giving a symbolic present. He can help him in his work or ask one of his children to do so on his behalf.

In addition to mobilising local resources, growers call on informal external financing. This is the largest funding potential. PÉLISSIER (2000) considered that gardening for on-farm consumption was being replaced by production sectors that require technical facilities and hence investment that small farmers could not make. They would need financial means for sustainable development operations on their farms, acquire motor pumps, purchase inputs and hire workers. For potatoes, this funding is from the *Maï Gida* (chiefs or partners) on the 'small market' in Niamey. These import potatoes from abroad (Nigeria, Burkina Faso, etc.) for consumption by the population and buy the farmers' crops at the end of the season. The credit that they provide varies according to growers' requirements. It can be in kind (planting material in particular) or in cash for purchasing other inputs. It is also awarded to farmers for economic and/or social requirements. The amount can exceed CFAF300,000.

Confidence, a necessary condition for loans from *Maï Gida*

Relations between growers and traders are established over a long period of time on the occasion of purchases of planting material and the sale of the crop to the same *Maï Gida*. As time goes by, the two parties gain confidence in each other. When a grower needs funds or inputs he can ask his *Maï Gida* directly. Credit with *Maï Gida* has become a quick nearby loan for growers that is comparatively effective.

> 'When the cool season begins, I won't have to go to Niamey to fetch the planting material. I just telephone him [the *Maï Gida*] and he sends the material to my house' (interview with a large potato grower, Kochilan Touareg, on 24 April 2013).

The awarding of credit by *Maï Gida* does not apply to all growers to the same degree. A grower may take all his seed potatoes on credit or possibly just a proportion of them. The credit allowed by traders is strongly related to the extent of the confidence established between the *Maï Gida* and the grower. Those who benefit from strong trust can even in turn stand guarantee for small or new growers. This privilege earns them respect but also power in society. They can run the largest farms and employ labourers and sharecroppers. In fact they become second level *Maï Gida*. Young men and women do not benefit from credit from traders. The traders do not trust the young men as they do not know them well and prefer to do business with their parents. And the *Maï Gida* do not wish to lend to women for fear of conflict with their husbands.

The informal funding practices of the *Maï Gida*

Even if this is not formally mentioned, the credit awarded by a trader is not without implicit clauses. Growers have a moral obligation to sell their harvests to their *Maï Gida*.

> 'Every year, I sell my crop to the *Maï Gida* from whom I had obtained seed potatoes on credit. Because if there is no planting material on the small market, he makes an effort to find it. He goes as far as Gamkalé, Kollo, everywhere, even if he has to take the pirogue to go and get it' (interview of an old farmer, Bonkoukou, 26 March 2013).

> 'Someone gives you up to three sacks of potatoes on credit—how can you go behind his back and sell to another person? I think that's not good […] because if he doesn't lend you the seed and you can't buy some immediately you're not going to be able to grow any' (interview of a group of growers, Amsagal, 21 October 2011).

Nonetheless, the traders say that they do not oblige any grower to sell them his crop—the essential is for them to get their money back. But if the growers sell to them they find that this is just as normal as they deduct their loans from the returns.

This bond that enables some farmers to grow potatoes makes them dependent on the traders. The growers must pay back the loans as soon as the crop is harvested—the period during which they are at their most solvent.

Behaviour and strategies of growers and traders

As the aim of both categories of stakeholder is to make a profit, Minvielle (2000) considered that 'the notion of monetary gain enhances the gradual movement of small farmers from behaviours of 'social persons' to behaviours of 'economic persons': money changes the taste of money and the nature of the fundamental justification of the act of exchange, its objective, changes'. The grower's concern is not the availability of potatoes on the market. His behaviour is based on the price mechanism, even though its existence is not directly linked to the market. His main aim is to be able to make enough profit to pay off his debts and meet his requirements. In addition to the profits expected, traders wish to conserve their potato distribution monopoly. It is in their interest that the other stakeholders in the marketing chain should not have direct access to farmers' crops. Each if the two stakeholder groups develops strategies.

The strategies of a proportion of growers are aimed at circumventing the traders. They involve the storage of the crop using artisanal methods (burying or in a shed) and the diversification of marketing channels. Storage is also used by growers who have no undertakings with regard to traders. Storing a quarter or possibly half of the crop is above all a way to spreading sales over a period of one or two months in order to sell at better prices. Selling prices of potatoes fluctuate strongly during a single year but are stable in the long term. The first Imanan harvests were sold in Niamey at up to CFAF400 per kg. When large quantities of potatoes are on the market from February onwards, when all the growers harvest and must sell their crop, prices are at their lowest—average CFAF225. They rise to CFAF350 or more in March and April. Thus with only two months of storage, delayed sales make it possible to earn at least CFAF50 more per kg sold.

The diversification of marketing channels allows growers to sell their production without being observed by the Maï *Gida* on different markets in the capital and to a varied clientele (semi-wholesalers, retailers, pedlars and consumers). They benefit from the margin that would have been earned by the others—wholesalers and semi-wholesalers. The existence in Niamey since 2012 of a Potato Fair where any grower can have a stall is precisely part of this approach. However, growers can only sell limited quantities directly on the 'small market' because the *Maï Gida* controls the sales pitches. In addition, selling the crop to a *Maï Gida* is a guarantee of immediate payment. The grower can make his purchases and return home sooner.

Maï Gida strategies are aimed at intimidating growers. Some growers can use their income from potato growing to buy seed potatoes and inputs from NGOs and associations that seek to promote the crop. Seeing their control of supply weakening, causing their power over farmers to dwindle, the *Maï Gida* order selected seed. They can raise the funds required for making orders very early to be able to supply growers with selected plant material and maintain their dependence.

Another *Maï Gida* strategy is to intercept growers at Wadata bus station at the entry to Niamey, used for transport from the Bonkoukou zone. For the traders, this is just aid for growers with the transport of the crop to the small market. In fact it is above all a means of control to prevent circumvention of the *Maï Gida* and sales to other customers.

> 'When we take out crops to Niamey, our *Maï Gida* have employees (young men) that they send to Wadata to counter the numbers of sacks of potatoes. This is so that we won't sell them to other customers. They grab us even before we leave the bus. If it's 10 sacks, they must see them…' (Discussion with a group of potato growers. Amsagal, 21 October 2011).

When a grower bypasses his *Maï Gida*, the latter may refuse to sell him seed potato in credit in the following season. But to enable growers to benefit from better prices when supply is large in Niamey, the Maï *Gida* often ask them to hold back their crop. In this case they may offer an advance to growers who have an immediate need for money.

Finally, the *Maï Gida* profit from their close relations with certain growers to settle in the administrative district. They start by asking for land to lease for growing potatoes. Accompanied by their own workers or hiring local labour, they come and grow a crop each year. After a certain length of time they purchase the land and bring their families. The most sought-after land is that which is best situated.

Conclusion

Potatoes have not only become a solution for the endemic food crises in Imanan but also a source of income that is resulting in a positive upsetting of social practices. But only farms that can mobilise sufficient resources (labour, capital and water) can make the crop a success. The lack of appropriate organisation of the potato sector combined with the weakness of funding alternatives mean that growers cannot become independent of the *Maï Gida*. In fact, the latter form the strong link in the sector. They control sales and intervene in production.

It is important to find alternative sources of funds so that growers can master their production process and for potatoes to play a full role in improving the living conditions of the people in Imanan. It would also be necessary to have an objective assessment of the borrowing and repayment capacity of farmers so that they can benefit from loans that match their requirements and so that their integration in the market is accompanied by profits that allow them to invest in their farming systems and even set some cash aside as savings.

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Conclusion

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New environmental opportunities

After 30 years of drought in the whole of the Sahel, rains returned in the first decade of the 21st century. This is a particularly strong trend in the central part of the Sahel, although the humid conditions of 1950-1969 have not been reached, and less marked in the western Sahel where drought lasted longer until the end of the 2000s.

In response to this return of rainfall, a regreening trend was observed in practically the whole of the Sahelian strip during the period 1981-2011. The resilience of vegetation concerns the herbaceous stratum in particular; this seems to have considerable recovery capacity, even after the droughts in the 1970s and 1980s. These field observations were made in particular in the agropastoral systems in the Gourma in Mali. Although their reappearance is less spectacular, the population of ligneous plants also seems to be in the process of regeneration after the recent increase in precipitation and the recharging of groundwater. These observations were made on the *Faidherbia albida* acacia population in Senegal.

Perceptions that tend to correspond to the ongoing changes

Even if rural societies who very often know nothing about the notion of climate change do not perceive or interpret current climate change in the same terms as those of scientists, they see—in Senegal, Benin and Niger—the recent change in the average climate and its annual variations, as observed by climatologists. This matching of local social perception and scientific observations of the climate is particularly good when climate changes are rapid, can be seen by everybody and they have an impact on ways of life and production volumes. Rural people in Senegal make a clear distinction between the environmental situation of some 20 years ago when drought was a stress factor and the present conditions in which farmers no longer perceive the climate as a major constraint, thanks to the return of rain and in spite of its interannual variation. In contrast, in northern Benin where the scientific reality of climatic changes is much less marked farmers' perception differs markedly from observations—in one direction or the other.

Cultural and adaptive innovations

While crop and livestock farmers clearly perceive changes in the climate they also adapt very rapidly, displaying considerable capacity for reaction and spontaneous adaptation. Particularly clear examples have been found in Senegal. In both the Niakhar observation zone (in the centre of the Senegalese groundnut production zone) where long cycle (110-120 days) Sanio millet has been reintroduced and spread throughout the Sine after disappearing nearly 30 years ago, and in the Senegal River Valley where sowing periods have been adjusted, changes in farming practices have been observed that have direct links with recent changes in the climate and with no intervention by researchers or development stakeholders. The Escape project has thus shown that a shortage of economic and technical resources did not mean that family farming was incapable of adapting. Even without investment, this category of farming innovates according to its resources and for cropping performances that enable farmers at least to live and stay on their land.

The innovations currently used in West African farming types and that give them dynamism are not either only or mainly responses to the variability of climates and natural resources. On a more overall and deeper basis, small family agriculture adapts to the major economic, demographic and political evolutions that change the features of its territory. Whether focused on crop farming or animal husbandry, whether they are near the coast, in the Sahel or in forest, rural societies and then their socioeconomic organisation and farming system adapt and change continuously. Among other things, innovations include the emergence or generalisation of new commercial crops and production, such as cashew nuts and soya in Benin, water-melons, cattle fattening and horticulture in Senegal and potatoes in Niger. These changes are also accompanied by new agricultural practices, with modified farming calendars (sowing date and crop rotations) and ever-broader diversification of extra-agricultural activities: crafts, trade and handling work according to the increasing needs of towns. It is true that not all these innovations are direct responses to climate change but they are certainly sources of income that help to reduce the vulnerability of farms, especially in the face of the climate. Here, they help to strengthen the capacity of small family farming to withstand climatic disturbances.

Migration: one component of a self-adaptive system

Seasonal long-term migration of rural people in Sahelian Africa is often considered to be a response to worsening features of the environment and the climate. All the studies focused on this question after the major droughts of the 1970s and 1980s have shown that these ecological crises have caused an increase in domestic (rather than international), circular and short-term migration, especially in the poorest families and for women and children. We have found the same migratory pattern in Niger and above all Senegal in the recent climatic context marked by alternating extreme contrary events (droughts and then floods), with the drought years being marked by an increase in seasonal migration, especially of young people and women. Here, widespread migration is an adaptive, reactive response which takes shape from a threshold defined by strongly degraded farming conditions. However, even in this situation migration cannot be considered as the failure of self-adaptation. At all the sites that we studied, migrants maintain an economic link with their families that remain in the village; they participate directly or indirectly in food security and sometimes facilitate the development of new activities on the original farm (transfers of financial, material and technological resources).

Although migration is linked with climatic conditions, it does not stop during years of rain and good harvests. On the contrary, the source villages maintain a continuous flow of migrants to ensure the cash requirements of families and individuals who usually consume a large proportion of their farm production. Large numbers of adult men migrate during the dry season to accumulate money for the survival of their households or for productive investments. But young people (girls and boys) attending schools also migrate during the rainy season to fund their education or to make up a dowry. Finally, migration—even disconnected from the climate factor—contributes to keeping rural households on the land as they are less strongly dependent on farming. This is the case in the groundnut zone where, among other factors, the crisis in the groundnut sector and advanced soil degradation have resulted in comparative regression in agriculture to the benefit of the non-agricultural sector—driven by trade, crafts, transport, migration, etc. These also favour the reduction of poverty (and especially food poverty) on farms in the process of decapitalisation. Finally, they make it possible—with no credit available—to earn the extra-farm income required for farms in the capitalisation phase. In short, when migration is strongest it responds to climatic and environmental shocks, but in return also tends to reduce the vulnerability of the people who stayed in the villages and to enhance agricultural innovation. Here, like a retroaction loop, migration thus increases to varying degrees according to the context the capacity of farms to adapt to climate change.

New climate risks

After experiencing the historical droughts of the 1970s and 1980s, the Sahel is now wetter and greener and ecosystems and the populations know how to benefit from the new situation. But although this book rightly shows the rapid resilience of natural and anthropic systems and the great adaptaion capacity of the population, the overall picture cannot be edited. The Sahel is not to become accustomed to a new climate but must face up to an extremely changing one.

Indeed, although the recovery of rainfall has been observed clearly in the Sahel, detailed analysis of the hydrological cycle in the region shows that the increase in annual annual rainfall depth is accompanied by a continued decrease in the number of days of rain and hence an increase in violent events (very strong storms). The situation is typical of a strongly variable climate with an intensitifaction of the precipitation regime with alternating hydrological extremes such as droughts and floods rather than being an indication of a return to the former humid conditions that prevailed in the 1950s. As has been noted, dry years are not a thing of the past. The Sahel has experienced at least four major food crises at the beginning of the 21st century—in 2003, 2005, 2010 and 2012. Except for the 2007-2008 crisis caused mainly by the excessive volatility of world foodstuff prices, food crisis periods result from problems of availability caused by droughts. At the same time, floods with strong socioeconomic impacts are much more frequent that in previous decades. Local situations featuring the flooding of fields, strong winds that lodge crops, rapid rises in water levels in low-lying land that submerge crops and decimate flocks and herds, soil eroded and/or runoff have become in addition to droughts regular catastrophes that crop and livestock farmers have to face.

Although the recent increase in rainfall that allows somewhat more abundant vegetation and the recurrence of violent rainfall events are the most visible signs of climate change, West African farmers consider that they are accompanied by the warming of the surface of Africa since the 1950s, a phenomenon that is much less clearly perceived but nonetheless undoubted. The hottest periods of the year are those most affected, and especially the spring when steadily increasing temperatures are 2°C higher than they were 60 years ago. The amplification of the annual temperature cycle consists mainly of an increase in night temperatures, with daytime temperatures remaining stable. The causes of this have not yet been established. In spite of the fact that temperature is central to the study of water and energy balances and that warming is found in all climate change scenarios, reaching +2 °C to +4 °C at the end of the century, it has been the subject of many fewer studies than precipitation.

But it is nonetheless a new constraint that African farmers may face in the future, with a negative effect on crop yields, livestock and cultivable areas as soon as the +2°C threshold has been reached. A joint study by IIASA and FAO considers that the area that can be used for cereal crops in West Africa will decrease by 7 to 15%, depending on the temperature rise scenario considered (+1 to +3ºC) (Fischer *et al.*, 2002). The temperature increase in the mid-21st century—of more than 3°C in certain places—is so great that there will soon be no equivalent in the African climate in recent history. Although this warming is already visible in climate observations, it is nonetheless less well perceived by the rural populations questioned as heat is omnipresent in rural zones and the harmful effects on agricultural production and health has not yet been felt clearly. Without perception of the changes, it thus seems difficult to develop adaptation strategies, especially as the climate in Africa in the decades to come will be totally new in human memory in terms of temperature, with warming whose speed and intensity could exceed the adaptation capacity of African populations.

Lasting constraints and vulnerabilities

Demographic data is of prime importance in development and the environment. Strong population growth exerts strong pressure on the natural resources of the continent and weighs heavily on economic growth, in particular because of the very high rate of dependence. A study by Ndulu (2006) thus shows that three-quarters of the overall negative gap between the per capita growth rate in sub-Saharan Africa and that in other developing countries from 1960 to 2004 is accounted for by demographic factors.

Demographic growth in Africa is the greatest of all the continents and the gap with the rest of the world is still becoming wider. As the groups of childbearing age will continue to form a large fraction of the population and because of the inertia of demographic phenomena, population growth will remain high and the age pyramid will remain young for several decades to come. According to the mean hypothesis of the United Nations, the population of Africa will have doubled by 2050, reaching 2 thousand million, that is to say 22% of the world population, and 27% will be less than 15 years old (United Nations, 2009). Although the rural African population is in a downward phase, the numbers will continue to grow until 2050, increasing from 592 million in 2007 to 764 million en 2050. Africa will account for 27% of the world's rural population in the mid-21st century (United Nations, 2008).

This original demographic movement obviously has effects on African economic development and in particular the development of agriculture. Today, farmers in the southern Sahara use about 200 million hectares of land (Roudart, 2010). However, the continuous degradation of cultivated land and the growth of the agricultural population can only cause a rapid extension of farmland. For reasons of poverty, the great majority of West African farmers are unable to acquire farming techniques likely to increase soil productivity and their only choice is often that of using the land until it is no longer suitable for farming or to gain new farmland in forest and prairie areas (as in Niger and Benin). When land reserves have been exhausted, as is the case in the part of Senegal studied, the natural growth of the number of farming households results in the rapid division of fields and a considerable decrease in the area of agricultural land owned. Overall, in many parts of West Africa, landholding pressure, excessive or unsuitable agricultural activities, intensification—often poorly managed—to meet the food requirements of a growing population and repeated droughts (or violent precipitations) trigger soil degradation and erosion processes, surface crust and runoff, loss of fertility and a decrease in crop productivity. African farmers rarely have the capacity to make an effective, sustainable response to these challenges and constraints.

Environmental changes and adaptation strategies analysed at the local scale

Characterising the evolution under the effect of human activities, the climate and the environment in the coming decades and envisaging effective adaptation options for the rural world are made all the more difficult by the great regional disparity in environmental changes. Although a tendency for regreening after the return of precipitations has been shown, especially in the agropastoral ecosystems of the Malian part of the Gourma, there is also proof of the degradation of ecosystems in the Sahel. This is the case in the Fakara region in Niger where fallows are less productive than they were 20 years ago and where surface soil erosion, a decrease in plant cover and an increase in runoff coefficients are markers of a degraded environment. In addition, the clear contrasts in climate evolution in the Sahel make analysis of trends and projections at large scales complex overall. For example, the warming observed in West Africa for 60 years is not homogeneous; it is stronger in the Sahel than in the Sudanian and Guinean regions. The return of rainfall is more visible in the central Sahel but seems to be later in the western part where the drought has lasted longer. Furthermore, the climate scenarios maintain this contrast between the western Sahel, where precipitation is considered to be decreasing, in particular with the lateness of the monsoon season in comparison with the current period, and the central Sahel that is considered to be receiving more rainfall at the end of the winter season. The contrast in rainfall trends between the western and central Sahel is not seen in temperatures. On the contrary, these show warming on a latitudinal gradient between the northern regions of the Sahel, with more warming, and those of the south. These regional disparities create different degrees of vulnerability in West Africa, where it would seem that the western part could be more affected by droughts, the northern part threatened by strong warming and the central part exposed to increased risk of violent rainfall and flooding. All this increases the complexity of what scientists say about the evolution of the climate and the environment in the region and about the ways to adapt.

Likewise, adaptations are often only designed at local or territorial scales giving the responses contributed by societies a very variable or even heterogeneous character. Both adaptation and adaptation capacity depend on the context in which they take shape. They vary not only according to the level of economic and technological development of the territory but also according to social norms and cultural values. However, adaptation scales are not totally independent either. The capacity of a household to face climate risks results to a certain extent from a favourable community environment, and the community's adaptation capacity is a reflection of the resources and processes used by the region or country. Adaptations thus vary from one country to another, from one community to another, between individuals and social groups and according to the passing of time. Adaptation is neither easily reproducible in all socio-spatial contexts nor necessarily constant in time, making it more difficult to plan on a large scale.

The advantage of the interdisciplinary approach and observations over long periods

Through the interdisciplinary mobilisation that it triggered, the Escape project has been an ideal framework for starting true dialogue between the scientific communities. This is focused on a common aim defined by the climate and environmental changes in West Africa. Indeed, the relations between humans and their environment are set in complex economic, social and political configurations that must be examined and related to climate and environmental phenomena using an interdisciplinary approach. The latter is crucial for addressing the question of adaptation to environmental changes where the response of societies is set in global social changes. There is a real need for a diversity of viewpoints, for sharing and comparing approaches centred on the question of environmental changes. Bridging gaps between different communities often takes longer than applying a single scientific discipline; joint subjects for study, a shared language and fields in which the different disciplines involved must be defined. The first step has been taken with the implementation of this interdisciplinary study centred on the same investigation. This investigation must now be continued and the sustainability of the approaches maintained beyond the Escape project. But these are actions to be conducted over a long period, that is to say under conditions that are often not very compatible with the logic of projects and publications that is a feature of the way in which research operates.

Furthermore, the results described here show that the challenges resulting from the complexity of relations between humans and their environment in a context of climate change cannot be gathered without long-term observations of the climate-society system. The continuity of meteorological and sociological observations is very important for detecting changes in progress, understanding the causes and anticipating the consequences in order to develop strategies for reducing the possibly harmful effects of these changes.

The monitoring facilities focused on populations in Niakhar, on the environment (Amma-Catch) in Niger and Benin and on agro-ecosystems in the Fakara in Niger are a very good example of this. Finally, the great disparities observed not only in the evolution of the climate and also in ongoing societal changes in West Africa underline the importance of conducting multi-site and multi-scale comparative approaches, placing in parallel the regions with contrasted environmental and socioeconomic constraints.

Research to be carried out on anticipatory adaptation

A few lines on future research are needed before concluding. Our work has strongly addressed spontaneous, reactive adaptation. Reflection remains to be conducted in anticipatory adaptation—frequently promoted by politicians and scientists for its ability to reduce the social, economic and ecological costs of change. In agriculture, possessing effective tools for the management of climate risks can bring true value-added to the adaptation strategies of African populations faced with the issues of food security, population growth and climate change and that can directly affect political balance. But these tools are still used little or not at all by farmers in spite of the proofs assembled by research programmes on their acute awareness of the climate risk, on the potential of climate information in planning and decision making and on recent progress in forecasting climate fluctuations (beginning of the rains, dry sequences) days or even months ahead. The many reasons for this contradiction include lack of knowledge about matching the procedures for the use of the information generated and farmers' requirements (scales of space and time, forecasting period, degree of confidence), about the most effective technical or organisational responses to climate fluctuations (changing farming calendars, making use of water, diversification of work, financial instruments such as loans and insurance for example) and about the way farmers can incorporate and appropriate these risk management tools developed by research in their own practices. In addition, this planned adaptation takes place at public authority level and at territorial scale; decision makers who can have access to the climate information produced by scientists are thus involved. Although the approach must take into account the uncertainty inherent in climate forecasts, it assumes nonetheless a clear perception of the uncertainty, the risk and the conditions that will change. In addition, this adaptation must be detailed and reflection carried out on its limits according to different farming systems and climate evolution scenarios in the west, centre and north of the Sahel in order to avoid any maladaptation and to integrate it in an overall agricultural development strategy for the region.

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The future of West Africa depends on the capacity of its agriculture to ensure the food security of the population, which should double in the next 20 years, while facing up to the new risks resulting from climate warming. Indeed, the changes in temperature and precipitations already operating and that should become more marked will have serious effects on agricultural production and water resources in this part of Africa in the near future.

One of the keys to meeting this new challenge is the adaptation of rural societies to climate risks. To gain better knowledge of the potential, processes and barriers, this book analyses recent and ongoing trends in the climate and the environment and examines how rural societies perceive and integrate them: what are the impacts of these changes, what vulnerabilities are there but also what new opportunities do they bring? How do the populations adapt and what innovations do they implement—while the climate-induced effects interact with the social, political, economic and technical changes that are in motion in Africa?

By associating French and African scientists (climatologists, agronomists, hydrologists, ecologists, demographers, geographers, anthropologists, sociologists and others) in a multidisciplinary approach, the book makes a valuable contribution to better anticipation of climatic risks and the evaluation of African societies to stand up to them.

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