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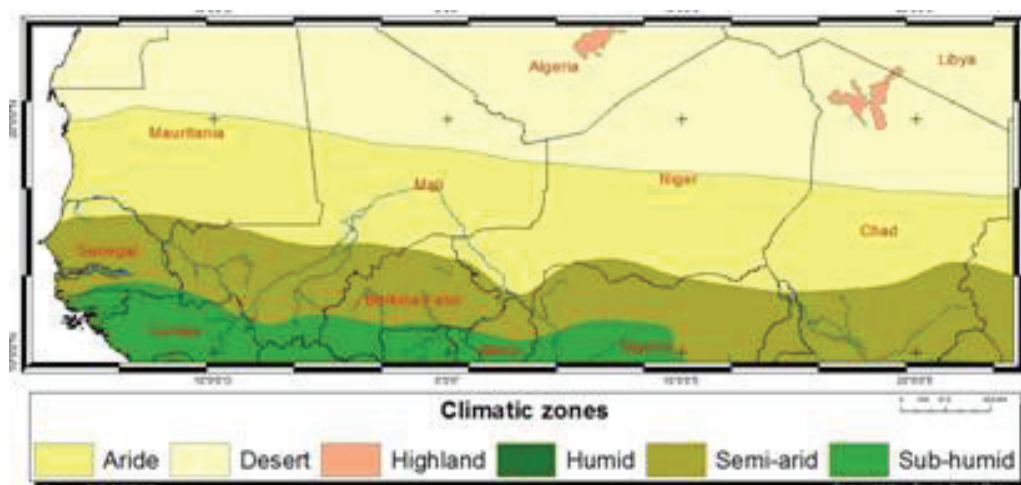
# Crop–livestock production systems in the Sahel – increasing resilience for adaptation to climate change and preserving food security

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## **INTRODUCTION**

Rural people in the Sahelian part of Africa rely mainly on crop–livestock activities and natural resources for their livelihood and food security, and to provide food for urban populations. For centuries, these activities have been adapted to the changing environment, as spatial and time variability (seasonal and inter-annual) of rainfall have always been specific traits of this agro-ecological zone (especially in the last four decades). This zone is defined as the southern border of the Sahara desert, characterized by low and unreliable annual rainfall, usually between 200 and 600 mm/year, along a positive gradient southward and occurring mainly between June and October, defining two main climatic zones, arid and semi-arid (Figure 1). Apart from a few secondary towns and major cities (such as Dakar and Bamako), the majority of the population (more than 70 percent [FAOSTAT, 2010]) live in rural areas where they practise agriculture. Livestock farming in the Sahel has been a traditional activity for centuries based on common use of resources (water, rangelands) and regulations. Societies have built their organizations and interactions on herd, pasture and water management (Bonfiglioli, 1988; Ancey *et al.*, 2009) and various exchanges with the “outside world” (Khazanov, 1984). Grazing systems traditionally fulfil various functions through diversified and accurate use of livestock capital (sales, gifts, loans, distribution, inheritance and even thefts): organization of resource management, social recognition, collective risk management, collective food security management and social reproduction. To secure their families’ livelihoods, these populations have been adapting their production systems and way of life to cope with uncertainties. Nowadays, they are faced with new challenges such as high demographic growth (4 percent on average), climate change, environmental concerns and global market changes, which have had major local impacts on their production system organization, dynamics and viability. We shall discuss here how livestock production sys-



**Figure 1. Agro-ecological zones in the Western Sahel**

Source: FAO (Agro-ecological Zoning Database 2000).

tems in the Sahel, associated with cropping activities or not, have been shaped by this highly variable environment, and what can be said about their ability to cope with the new challenges and maintain their production systems and way of life (i.e. resilience). We will analyse how public policies could enhance their adaptive capacities to further changes and ensure population food security. Whereas the main ecological and socio-economic characteristics of production systems in the Sahelian part of Africa are broadly similar from Senegal in the West to Ethiopia in the East, we will focus our description on the countries of the Western part of the Sahel (Senegal, Mali, Burkina Faso and the Niger).

## CROP-LIVESTOCK PRODUCTION SYSTEMS IN THE SAHEL

### Characteristics and distribution

In this study, we look at crop-livestock production systems in the Sahel as defined by Sere and Steinfeld (1996), the FAO global classification of livestock systems that has been widely used and recently refined in a study on global livestock production systems (Robinson *et al.*, 2011), combining agro-ecological, production and livelihood data. Such systems, in arid and semi-arid areas, can be composed of:

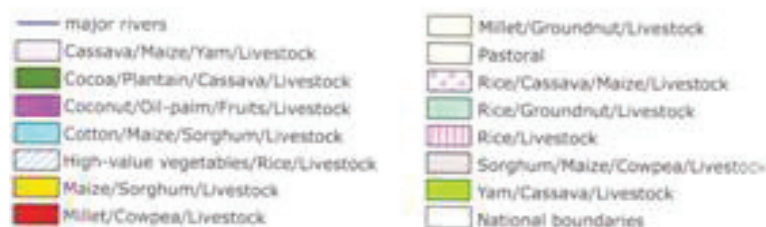
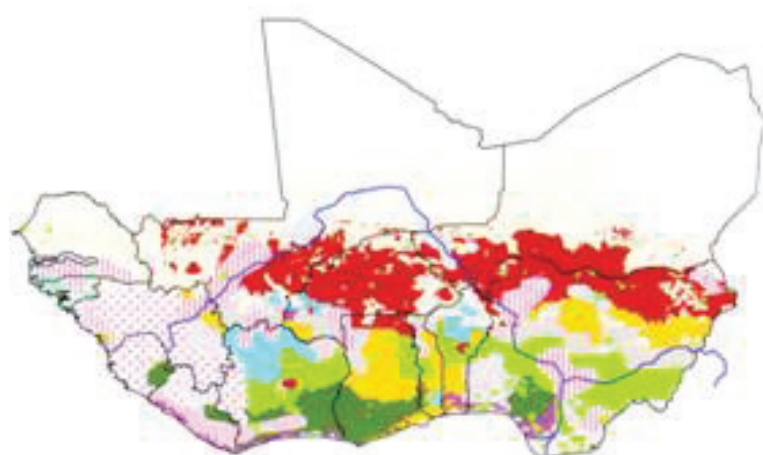
- livestock only grazing systems;
- rainfed mixed crop-livestock systems;
- irrigated mixed crop-livestock systems.

These three types of systems combine crop (mainly millet, cowpea, sorghum, cotton and groundnut) and livestock activities (cattle, sheep, goats and camels) in different proportions. Figure 2 shows the distribution of such major crop-livestock production systems in West Africa. These are important systems both for agriculture and livestock production, and in terms of livelihoods in the whole West Africa, especially in four western Sahelian countries (Burkina Faso, Mali, the Niger and Senegal), where they breed the majority of the livestock population and contribute more than 30 percent to the agricultural GDP – compared with 17.2 percent in the whole of West Africa (see Table 1).

**Table 1: Importance of livestock population (x1 000) in 2004 in western Sahelian countries**

	Cattle	Sheep	Goats	Contribution to agricultural GDP 2000 (%)
Burkina Faso	5 200	7 000	8 800	34.7
Mali	7 500	8 364	12 036	48.8
Niger	2 260	4 500	6 900	37.4
Senegal	3 100	4 700	4 000	30.9
TOTAL	18 060	24 564	31 736	37.95
TOTAL W Africa	42 466	56 850	69 779	17.2

Source: Ly, Fall and Okike (2010).

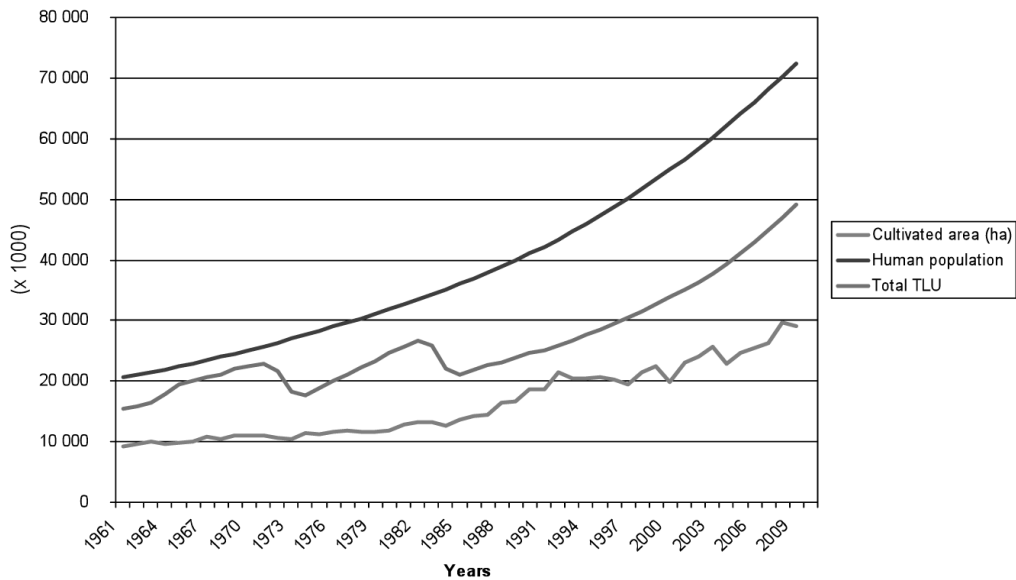


**Figure 2. Distribution of major livestock production systems in West Africa**

Source: Ly, Fall and Okike (2010) from Fernandez-Rivera *et al.* (2004).

In western Sahelian countries, the rural population, living in settlements of less than 5 000 inhabitants and involved in livestock farming systems, is extremely significant: at 60 percent of the total population. This share is expected to decrease down to 40 percent by 2050 (Ly, Fall and Okike, 2010).

The organization of these systems relies mainly on mobile livestock using rangelands and crop residues, from nomadic or transhumant mobile pastoral systems in the north (for the livestock only grazing systems) to more or less seasonally mobile livestock systems in the southern part (rainfed and irrigated mixed crop–livestock systems). The unconditional need for mobility of livestock (as a whole or partially), and also for families, results from rare and scarce natural forage resources, while feed is unavailable or unaffordable owing to geographical isolation, high transportation costs and low purchasing power.



**Figure 3. Dynamics (x 1 000) of human population, cultivated area and Tropical Livestock Unit (TLU = cattle + small ruminants + camels) in four Sahelian countries (Senegal, Mali, Burkina Faso and the Niger) between 1961 and 2009**

Source: FAOSTAT (2012).

Actual trends (see Figure 3) show that population and livestock growth is likely to lead to more tension on land use between crop activities and pasture use.

Closely connected to an uncertain environment and variable natural resources in arid areas, the pastoralist's livelihood system in the Sahel depends on mobility, herd accumulation or ability to diversify practices and activities. The use of rangelands ranges from nomadic to sedentary lifestyles, with varied and changeable schemes of mobility (Bonfiglioli, 1990). Arid areas usually being open, in a sharing economy, the access to natural resources is based on several usage rights in order to ensure mobility and reciprocity (Thébaud, 2002). This access to land is combined with a family organization and control of production factors that varies from a patrimonial to a shared herd management (Ancy *et al.*, 2008). Women and younger men may own a part of the capital in livestock. With the opening of the pastoral areas to more diversified societies and to technical interventions of development, support to reciprocity became weaker (Sutter, 1987; Watts, 1987).

More broadly, rural agrarian societies, which integrate more or less livestock, rely on several flexible combinations of activities. In the crop and pastoral systems, farming systems oriented towards livestock (milk, cattle) and/or crop (dry cereals, groundnuts, etc.) production are more or less complementary in their land use, creating among all actors (among agro-pastoralists, as well as between agro-pastoralists and pastoralists) social relations ranging from complementarity to competition. These systems show signs of recomposition with search for off-farm incomes, and some include speculative exported crops (onions, niebe, cotton) (AFD, 2007). Moreover, they are connected to the world economy through the interventions of development, and through an increasing number

of agricultural families depending on off-farm incomes and remittances (Losch, Fréguin-Gresh and White, 2011). However, these adaptations of livelihood do not guaranty their food security.

In the crop systems, the tendential deterioration of revenues from agricultural production, added to the growing pressure on land and of demography, severely limits the prospects for the build-up of capital. These factors partly explain the rural exodus, mainly agricultural, even if the number of rural people is expected to grow in sub-Saharan Africa (Losch, Fréguin-Gresh and White, 2011).

### **Contribution of crop–livestock systems to livelihoods and food security**

At farm level, livestock provide not only part of the family food, but are also useful for crops through the use of manure and draught power. Importantly, livestock also provide an income to the economy of pastoral households, ensuring a means for saving, insurance and legacies. Livestock are therefore essential to the security and reproduction of the systems.

Locally, such systems contribute more and more to salary employment (Wane, Touré and Ancey, 2009).

At a regional level, although livestock numbers are still growing in the Sahel and contribute substantially to agricultural GDP (Table 1), their contribution to human consumption is not sufficient and does not respond to the increase of per capita meat and milk consumption because of low production levels and high demographic growth. As a consequence, trade deficit in livestock products is expected to increase (Ly, Fall and Okike, 2010).

### *Challenges for public policies and resilience of crop-livestock systems*

In a context of open economy, under the constraints of local and global climatic uncertainty, the absence of public protection makes the adjustments pastoralists have to make in economic and social terms to smoothing and sharing shocks and constraints more difficult. This makes people more vulnerable and accentuates inequalities.

At national and regional scales, it is often difficult for public authorities to support local production, provide access to social services and ensure food security, notably in addressing price volatility. For example, the current level of import taxes in the West African Economic and Monetary Union is among the lowest in the world; prices of exported crops are not defended (Nubukpo, 2011) and sub-Saharan African countries were unable to protect regional rural populations from the volatility of commodity markets in the recent food crises.

In such an uncertain pastoral environment, marked by climate risks and price volatility, public regulations of goods and services are particularly necessary to ensure food security (Janin and de Suremain, 2005).

### *Ecological functions*

Besides production and economic functions, the ecological functions of livestock farming gain importance on the policy agenda as environmental concerns emerge. Its contribution to soil fertility in mixed systems through organic matter transfer by livestock has been intensively studied and show higher yields in cropland than in production systems without

livestock (Landais and Lhoste, 1993; Hiernaux *et al.*, 1997; Manlay *et al.*, 2004). In grazing systems, livestock also contribute to biodiversity maintenance, water cycle enhancement and carbon sequestration in rangelands where grazing pressure is moderate (FAO, 2006; Mieke *et al.*, 2010; Toutain *et al.*, 2010). Greenhouse gas (GHG) emissions per output are important as forage and livestock diet quality are low but assessment of GHG emissions of such systems needs more accurate data. They also need to be balanced with other environmental and socio-economic services provided by livestock farming.

### *Social functions*

Grazing systems traditionally fulfil various functions through diversified and accurate use of livestock capital (sales, gifts, loans, distribution, inheritance and even thefts): organization of resource management, social recognition, collective risk management, collective food security management and social reproduction.

In recent decades, more and more livestock were integrated in agricultural systems as a complementary source of income and also as a means to improve crop production by making organic matter available for soil fertility (Landais and Lhoste, 1993). At the same time, owing to climate variability (grazing systems moving southwards) and strong demographic pressure (agricultural systems moving northwards), interactions between different grazing systems became more frequent, as land, forage and organic matter management and product exchange can attest. As a result, resource management evolved through livestock lending management, common social organization for water, pastures and soil fertility management, employment for herd or crop management, marketing organization, etc., developing a new social relationship inside and between crop–livestock systems. This is even strengthened nowadays as decentralization in all Sahelian countries aims to lead to the integration of the different land users in local organizations with the aim of improved management of land and natural resources.

## **RISKS FACED BY CROP–LIVESTOCK SYSTEMS IN THE SAHEL IN THE RECENT PAST**

### **Climate-related risks**

#### *Climate variability and prospects*

Climate variability is one of the major characteristics of the Sahelian area. This variability can be observed at time and spatial scale. Figure 4 shows that the inter-annual variability of rainfall in the Sahel is not something recent. Usual average coefficient of variation (CV = standard deviation/average annual rainfall) is around 30 percent. It is also clear that, during the last century, the Sahel experienced different periods, a wet period (1950–1968) and a very dry period (1972–1995). The current period since 1996 is very dry with a few wet years. Together with this highly variable rainfall over time, the other main feature is a highly spatial variability of rainfall owing to its stormy nature during the monsoon. As a consequence, rainfall can not only be very heterogeneous on the same day at a 10-km distance but also for the annual rainfall at a 20–30-km distance. Rural populations are familiar with these characteristics (see below) and their practices are adapted to time and spatial heterogeneity of rainfall.

The main risks occur when two to three dry years cumulate with consequences on main stocks, which run short (food grain stock, rangeland seed stock, animal body condition,



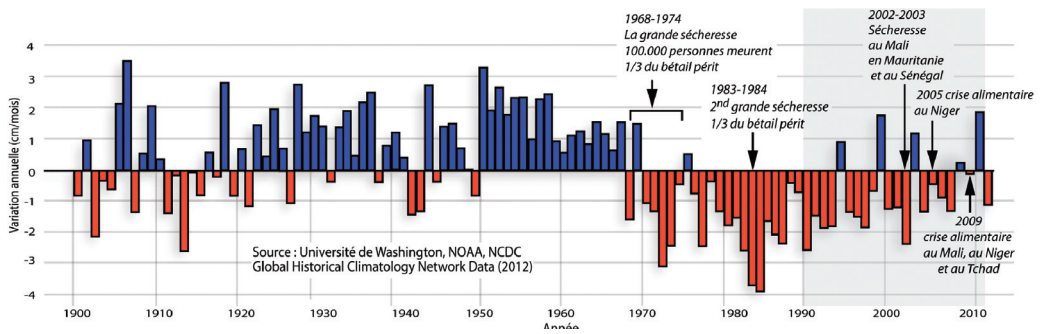


Figure 4. Variability of annual rainfall compared with average in the Sahel between 1900 and 2010

human health). This was observed in the early 1970s (1973–1974) and mid-1980s (1984–1985), with the severest droughts in the twentieth century with many people and livestock deaths (see Figure 4).

Actual trends for the geographic repartition of annual rainfall in the Sahel are still not so clear. Comparing isohyets for the period 1991–2009 with average annual rainfall during 1961–1990 (Figure 5), we can identify a smooth increase of rainfall northward. This is why some authors working on the dynamics of biomass estimates in the Sahel through a vegetation index refer to a “Sahel greening” (Bégué *et al.*, 2011).

In the future, climatic prospects do not seem so clear about rainfall in the Sahel owing to the complexity of the monsoon regime, which results in very different and controversial results from recent models (Hiernaux and Soussana, 2011). Temperatures are expected to rise in a range 1.8–4 °C, but local differences are likely to overshadow global trends and a main change might result in extreme events such as heat stress, drought and flooding (Thornton *et al.*, 2009).

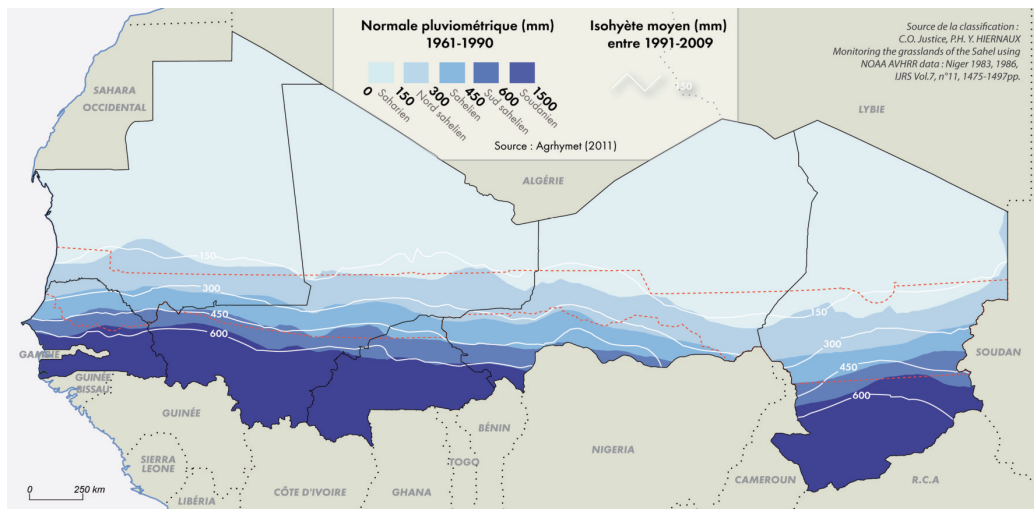


Figure 5. Isohyets in the Sahel during the 1991–2009 period compared with average annual rainfall during 1961–1990

## *Effect of climate variability*

### *Effects on distribution and production*

The positive rainfall gradient in the Sahel from north to south combined with high spatial variability can explain the distribution of the different production systems.

North to this 400-mm line, livestock systems are mainly mobile livestock systems (transhumant or nomadic, livestock only grazing systems) with lesser cropping activity up to the north. Livestock mobility, more or less linked to human mobility, is here a strategy to cope with resource uncertainty in space and time. Opportunistic management of resources has been described as a characteristic of these livestock only grazing systems and also as the best practice to produce and survive in this kind of environment (Benkhe, Scoones and Kerven, 1993).

Cropping systems in association with livestock activities (rainfed mixed crop–livestock systems) are widespread south of the 400-mm rainfall line and consist mainly of sedentary or semi-sedentary production systems. Livestock are generally kept around households where crops are grown and are fed on rangelands and crop residues. When annual rainfall is poor, livestock are frequently moved away for several weeks to find natural forage resources elsewhere, being driven by family members, relatives or sometime pastoralists (Toutain and Ickowicz, 1999). Crop productivity shows annual variations with coefficients of variation similar to those of rainfall. Variability of livestock system production is more complex to estimate. Very few studies and relevant figures are available for the Sahel at national level. We might argue that mobility allows pastoralists to alleviate this climatic variability, even if average productivity is lower than in other systems. See Table 2 for some usual performances of cattle and sheep under rainfed mixed crop–livestock systems or livestock only grazing systems.

### *Climate change adaptation*

From climate change as predicted by the Intergovernmental Panel on Climate Change (IPCC), expected impacts of climate change on livestock systems might be more important on livestock only grazing systems as their dependence on natural rangeland is much more important. Change in quality and quantity of feed, heat stress, water availability and more frequent extreme climatic events are expected, but there is an important need to better analyse these impacts in order to understand how livestock systems would have to adapt (Thornton *et al.*, 2009).

Climate variability or change already triggered reported changes in the management of production systems over the last decades, even if it is difficult to discriminate *stricto sensu*

**Table 2: Usual performances of ruminants under rainfed mixed crop–livestock systems and livestock only grazing systems in the Sahel**

	Annual reproduction rate (%)	Average milk production (litres/day)	Juvenile mortality rate (%)	Net offtake rate (%) *
Cattle	45–60	1.5-3.5	10–20	14
Sheep	85–91	-	11–15	18–25
Goats	93–96	-	20–25	17–19

\* net annual exploitation of herd production in heads

Source: Tyc (1994); Ezanno, Ickowicz and Lancelot (2005); Lesnoff, Corniaux and Hiernaux (2012).



climate-change adaptation measures from measures linked to the adaptation to other major drivers of change such as increase of human demographic pressure (Thébaud, 1990; Bonnet *et al.*, 2004; Ancey *et al.*, 2009; Thornton *et al.*, 2009; Ickowicz *et al.*, 2010; Bah *et al.*, 2010; Touré, 2010; Touré *et al.*, 2009):

#### *Crop-livestock systems*

- Increase in cropped area
- Change in sowing and harvesting dates
- Change in crop species
- Decrease in grazing cattle number but increase in sedentary draught and fattened cattle and in small ruminants
- Decrease in rangeland area vs cropped area
- More herd mobility in dry season because of less rangeland availability

#### *Livestock grazing systems*

- Change in livestock species contribution to herd composition. More small ruminants and less cattle owing to decrease in grass availability. In northern area, camels expanded
- Change in mobility pattern with longer distances, longer durations
- Herd routes moving southwards to more humid areas to find forage resources
- More conflicts with sedentary people in the south owing to competition for water and pasture resources
- Diversification of activities and income resources

### **Economic risks**

Strategies to manage risks as a result of climatic variability will have to be integrated with strategies driven by economic considerations.

Sahelian countries are dependant on the global economic environment, which was marked by an exceptional surge in food prices between 2007 and 2008; this trend continues today. Worldwide, the prices of cereals, in particular, have increased by 87 percent from the first trimester of 2007 to the first trimester of 2008 (FAO, 2008). This wide variation in food price reflects the growing uncertainty on global markets. It is often transmitted, though with great heterogeneity, to national markets (HLPE, 2011a).

The food crisis is often analysed as the result of uncontrolled variations of supply and demand at regional and local levels, owing to both structural and cyclical factors (IMF, 2006; Mitchell, 2008; RPCA, 2008a, b; FAO/OECD, 2011)<sup>1</sup>.

These phenomena have a real impact on food and nutritional profiles of Sahelian pastoralists. However, little information is focused on animal feed because of the weak and marginal volumes at stake and yet so vital to the security of animal productive potential in Sahelian pastoral and agropastoral systems in a context of climate change (Assani *et al.*,

<sup>1</sup> An exhaustive synthesis on the dynamics of price volatility and impact on food security is provided in HLPE (2011) and a synthesis on price volatility and transmission on local prices by David-Benz *et al.* (2010)

2011). In fact, the global market for animal feed is also affected because nearly 36 percent of the grain produced – mostly traded on world markets – contribute up to 50 percent of the composition of animal feed in general (Harder and Jung, 2008) and contribute more and more in rainfed mixed crop–livestock systems and livestock only grazing systems. The situation has become worrisome for countries highly dependent on cereals, especially for people in structurally deficit areas of the Sahel (RPCA, 2008a, b).

In this economic risk analysis, we describe very briefly the determinants, nature and effects of the food crisis on human populations and then focus on the impacts, often weakly studied, on animal populations at a territorial and/or micro scale.

### *Crisis in world prices of food and animal feed: transmission and volatility*

The price increase has affected all agricultural commodities, but not with the same magnitude (Figure 6).

The world price of rice began to flare in November 2007 before peaking at USD1 015 per tonne in May 2008. This represents an increase of 200 percent. Wheat had a steady increase from June 2007 and reached its peak of 126 percent in March 2008, then declined without returning to its former levels. International prices of maize showed a relative decline in the third quarter of 2007 and have regularly increased until May 2008. Regarding oil prices, which have direct impact on the costs of processing and transporting food and on the price of water in Sahelian boreholes, uncontrolled increases were observed with price levels multiplied by 2.49 between 2007 and 2008 with a peak in July 2008 up to USD1 225 per tonne of diesel.

Given the contagion effects that are due to the strong market integration, an acceleration of propagation of shocks is often expected, with transmission of the world price variations to domestic prices. However, this effect had a more or less direct impact according to the configuration of national markets and the extraversion of consumption patterns (Meuriot *et al.*, 2011).

Indeed, for animal feed markets, for which more than half the inputs come from imported grain (Harder and Jung, 2008), the increase in world prices has been strongly felt (Assani *et al.*, 2011).

However, price volatility in African countries is likely more endogenous. It is influenced by the ambivalent function of market segmentation, the configuration of which can either increase price volatility, preventing any possibility of compensation, or mitigate the effects of volatility (Meuriot *et al.*, 2011; HLPE, 2011a).

Moreover, it has to be noted that the effects of rising prices have been slightly smoothed for the Sahelian countries by favourable exchange rates between a weaker US dollar (the main currency in international trade) and the Franc Cfa, which has a fixed exchange rate with the Euro (Assani *et al.*, 2011).

### *Causes of rising animal food prices: case study of Senegal*

The origin of the crisis of food and energy is multidimensional and largely documented in particular by FAO (2008), HLPE (2011a, b) reports and the report for the G20 (FAO/OECD 2011).

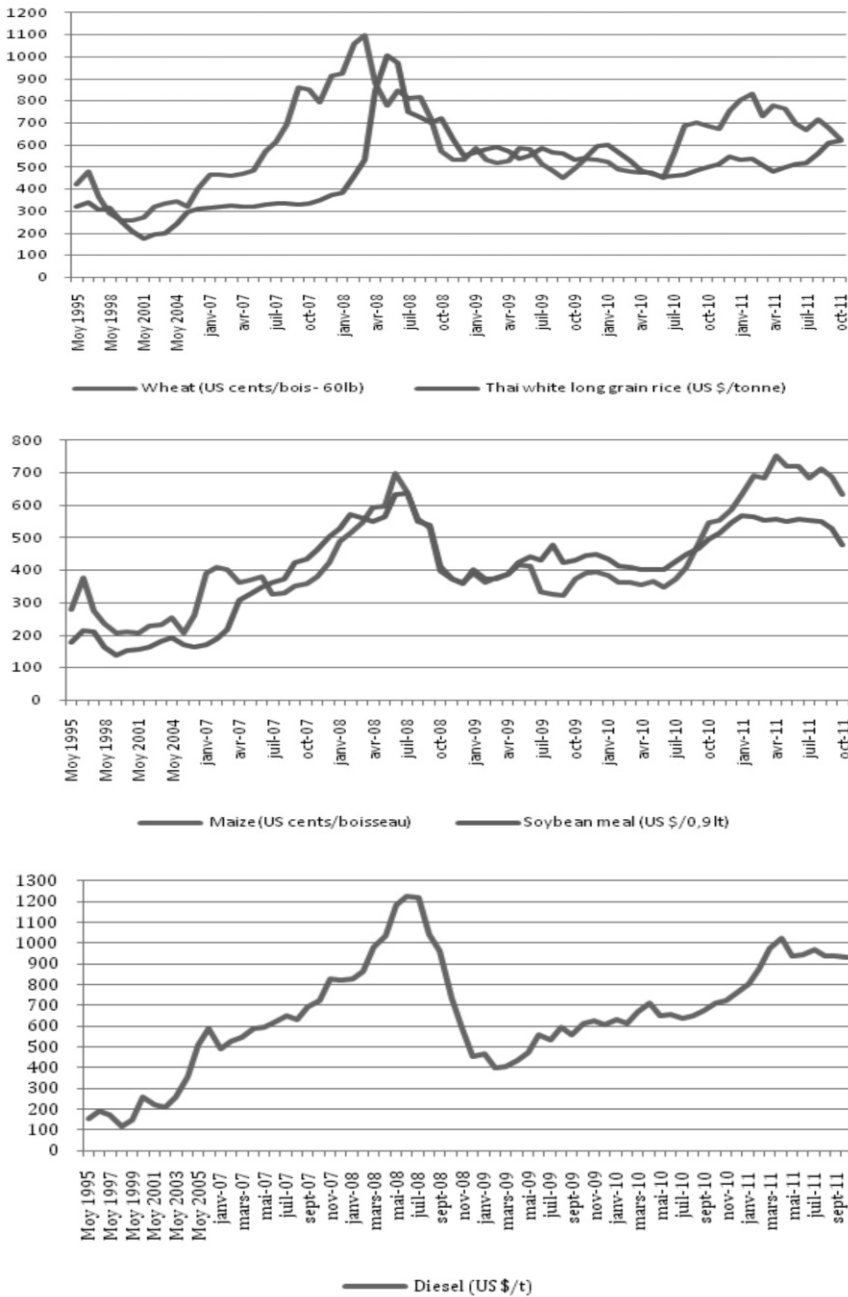


Figure 6. World price trends of cereals and oil

For animal feed, the imbrications of international markets and national markets dominated by imports of inputs have strongly influenced the prices observed in Sahelian countries.

However, these price changes do not come only from variations of international prices; phenomena of margins also played a role. For illustration, in Senegal, there were significant

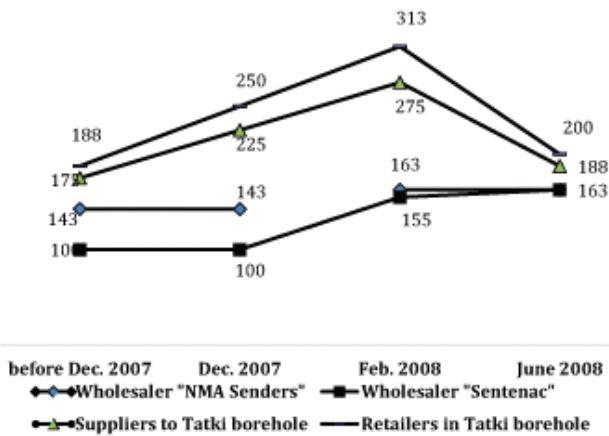


Figure 7. Evolution of the price of ruminant feed by type of seller (xof/kg)

differences in prices between various feed providers to pastoralists, the final purchaser. Until December 2007, the latter purchased animal feed at prices from 1.9 to 2.5 times higher than those paid at the cheapest factory (Figure 7).

#### *Effects of price increase on crop and livestock markets in the Sahelian areas*

One of the main consequences of the variability of grain prices lies in food security and nutrition vulnerability of pastoral populations.

Sahelian pastoral households often turn onto markets to sell animals and buy commodities like cereals (Wane, 2010; Wane, Touré and Ancy, 2010a, b). «Normal» or «unusual» movements of food and feed prices affect decisions on management and marketing of livestock in the Sahel. During the feed and food crises in 2007 and 2008 in Senegal, pastoralists came on livestock markets with unusual animal offers influencing market parameters through prices and quantities. For example, exceptional sales of small ruminants in February 2007 were realized during the period of feed crisis, which forced farmers to sell more to cover their expenses. The structure of sales of adult cattle has also changed. There were more beef proposed on the markets as well as cows with calves; thus showing the weakening of the pastoral micro-economic model (Wane, Touré and Ancy, 2010a). Such effects are similar to the ones in responses to drought, described in Gitz and Meybeck (2012).

Regarding markets, pastoral populations are also involved in trade exchanges without necessity and, sometimes, for opportunistic reasons. This behaviour assigns a central role to the “terms of trade” in agricultural markets. The terms of trade alternate periods of low and high variability, which is due mainly to the sharp fluctuations in grain prices highly correlated with harvest levels, which in turn are largely dependent on erratic rainfall in the Sahel.

The terms of trade have changed significantly for various reasons in Africa in relation to geographical and historical contexts (Dietvorst and Kerven, 1992). In the Sahel, especially in the Niger, because of the Fulani domination in the possession, management and marketing of animals and also owing to their specific dietary requirements, the terms of trade were

soon dependant on the relative values between livestock and cereals (Dietvorst and Kerven, 1992): mainly between cattle and cereals (Dupire, 1962; Baier, 1980; Bonfiglioli, 1988) and, more recently, also between goats and millet in Mali, for example (Wane, 2010; Wane, Touré and Ancey, 2010b).

Until the aftermath of independence, terms of trade were characterized by very high variability mainly due to significant price volatility strongly correlated to millet crop quality and therefore rainfall (Sutter, 1982). Today, phenomena combining climatic and economic aspects (speculative transmission of price increases, price volatility, effects of substitution of imports by local products) exacerbate the instability of terms of trade (David-Benz *et al.*, 2010).

In 2010, the Sahel once again experienced a deep crisis highlighting the vulnerability of pastoralists for food and nutrition (Figure 8). In Mali, for example, a comparison of inter-annual terms of trade goat-millet in 2010 largely inspired by biophysical approaches

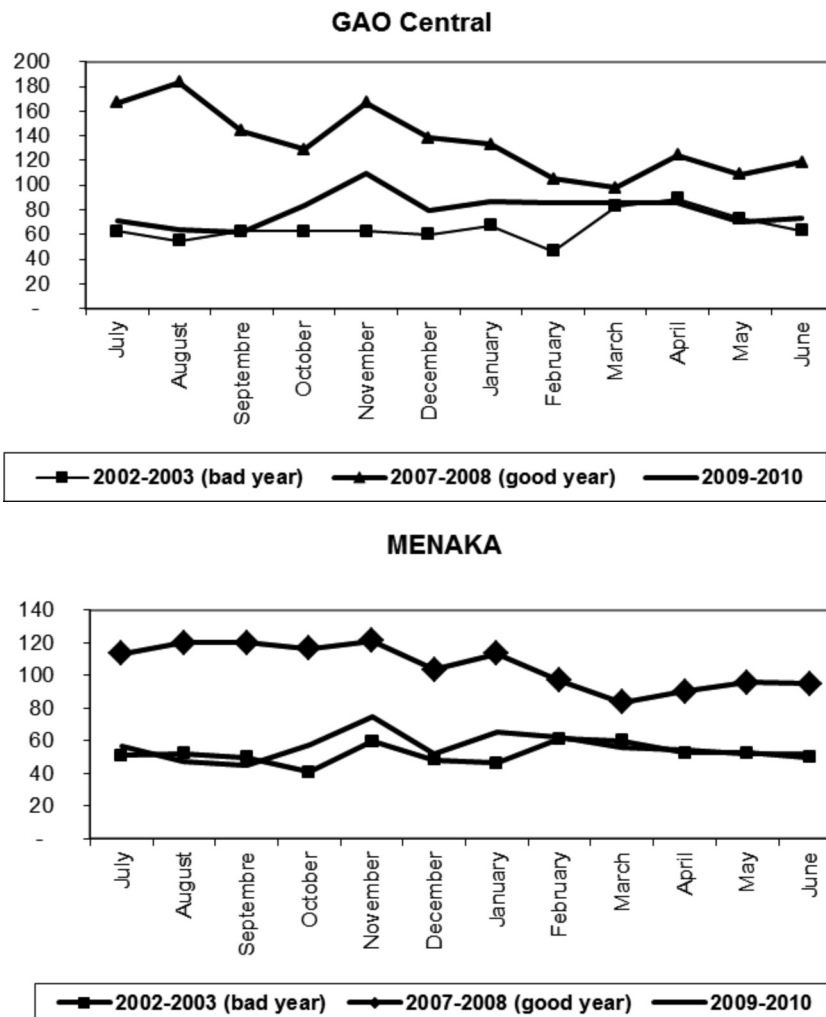


Figure 8. Inter-annual comparison of terms of trade kg millet/goat

proposed in the Sahelian context (Touré *et al.*, 2009), compares the terms of trade in 2010 related to good or worse years of the last decade, declared by the household investigated according to their perceptions. This allows us to obtain a relatively quick review of the crisis. With reference to markets in Gao central and in Menaka, the terms of trade goat-millet of the year 2010 are largely below those of a good year.

These two markets have terms of trade flirting with those observed during the worst years of the last decade. Although a slight improvement is noticeable after the harvest period in October, ongoing deterioration is such that by February 2010 (Menaka) and March 2010 (Gao central), the curve of the terms of trade merged with the curve of bad years (Wane, 2010; Wane, Touré and Ancey, 2010b).

As a conclusion, we could say that overlapping of markets at different scales (international, national, local) leads to transmission of higher prices and volatility but that the configuration of national markets, styles of consumption and especially public policy regulation have a mitigation effect (policy measures to contain inflation and to support the purchasing power: subsidies, price and stocks controls, simplification of market procedures, boost of local production and reconstitution of food réserves).

For Sahelian countries, it is needed and urgent to harmonize methods on market data collection and processing, to develop appropriate concepts and indicators in order to prevent food and nutritional crises and to develop a multidimensional approach to food security, taking into account the availability, access and use of food and the stability of production and prices. This dynamic must be articulated with the ongoing discussions within the Technical Committee of the Harmonized Framework jointly managed by the Comité Inter-états de Lutte contre la Sécheresse au Sahel (CILSS) and its partners (US Agency for International Development, World Food Programme, FEWS.NET, FAO, MIFRAC, IBIMET-CNR, CIDA, Care and the European Union).

## Land tenure risks

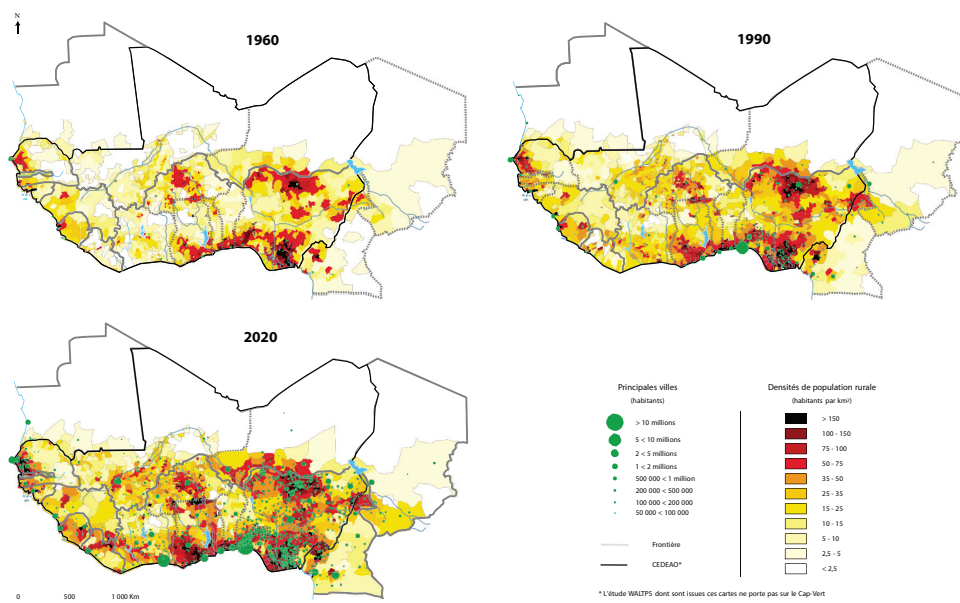
### *Land-use change, changes in the spatial distribution of production systems and underlying drivers*

Sahelian Africa has one of the fastest growing populations in the world. Population gains have been accelerating since 2000 (Figure 9). This demographic jump can be explained by a continuing high fertility rate combined with a fairly rapid drop in mortality rates. The total population for the Sahel region<sup>2</sup> is expected to double by the year 2030, to almost 100 million people, a scenario in the order of +2.5 percent per year. Urbanization will continue at a considerable pace, expected to reach +5 percent in the capitals. However, the rural population, which still represents 70 percent of the total population (as of 2010), will continue to increase and should remain the majority up until 2035.

The densification of rural areas is a central driver to the dynamics of land occupancy in the Sahel. Such a densification is occurring in originally thinly inhabited areas, which are subject to major spatio-temporal rainfall hazard, low productive and ecologically fragile.

<sup>2</sup> On the basis of CILSS member countries (Burkina Faso, Cape Verde, the Gambia, Guinea Bissau, Mali, Mauritania, the Niger, Senegal, Chad).





Source : Etude des perspectives à long terme en Afrique de l'Ouest (document de synthèse, 1998)

**Figure 9. Population of West Africa between 1960 and 1990, forecast to 2020**

Source: ECOWAS (2005)

Producers have adapted to these constraints by developing production systems based on extensive and mobile crops and animal production, all of which take up considerable space. Today, as it requires less financial resources, cultivation is developing more rapidly than livestock herding, an obvious advantage where purchasing power is low.

Consequently, cropping is making the greater strides and the effects of this are being felt in rangelands to the North in the form of both rainfed and irrigated agriculture. It is also gaining space in the forest areas to the South through a reduction in summer fallow and through wood harvesting. At the same time, livestock herds have recovered from the severe droughts of the 1970s and 1980s and are now on the increase.

Taking advantage of a fall in the incidence of trypanosomosis, livestock holders have settled down with their herds in the vicinity of the Sudanian zones, which offer easier access to the markets as well as proximity to the transhumance staging points.

In South Sahelian zones, the pastoral area is shrinking or being blocked by the double pressure of cultivation and urbanization. In these areas, the activities of livestock rearing and that of cultivation were once relatively independent. Now they are vying for access to the same territories or the same resources (water, land, forage, timber). These activities remain poorly integrated and are still based on low-intensive production systems that are technically not very productive, in addition to being space consuming. The mobility of the herds of Sahelian pastoralists is clearly hindered in today's environment.

The closing off of access points to rivers has become a serious difficulty in the wake of large-scale hydro-agriculture projects, such as can be found in the Senegal River Valley and in the Inner Niger Delta. The demographic pressure in the southern agricultural regions,

which has reduced fallow land and natural pastures, has led to the paradoxical situation today where the rainy season is a season when access to pasture is a thorny issue.

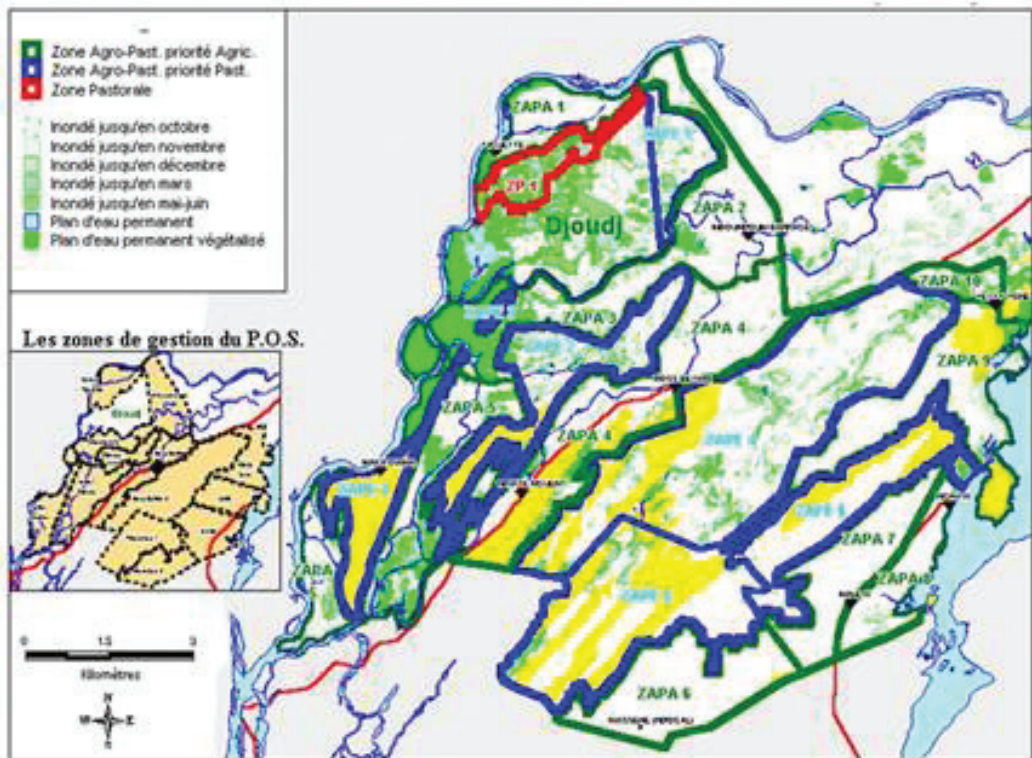
Land tenure and land use are thus major issues across the entire Sahel. Competition is fierce, sometimes resulting in violent conflict. Within this context of intense land pressure, traditional rules of access to resources are becoming less and less effective. Modern regulations, which in most Sahelian countries recently recognized collective land-use rights for pastoralists, are rarely implemented in the absence of land titles and enforcement procedures. Confusion abounds and the law of the strongest prevails, exposing modest producers without land-use rights to the risk of large-scale land appropriation.

### *Large-scale land acquisitions*

For several years now the African continent, and also the Sahel, has been affected by the phenomenon of large-scale land acquisition (HLPE, 2011b). Eager to raise capital and modernize their agriculture, many states have turned to private foreign investors. The consequences of these large projects for the host countries and their populations are not negligible. In fact, such projects are radically transforming regions. The investors often “sell” their project as an injection of development capital when in fact they are grabbing hold of resources principally used by the local populations but not formally owned by them (land, water). The contentious decision to favour agro-industry over family farming, the latter being viewed as unproductive and insufficiently market-oriented, runs the risk of foreign companies acquiring lands on a formal, enduring basis to the detriment of local populations. Moreover, produce on those lands is often destined for export: cane sugar, cotton, vegetable oils (groundnut, sunflower), biofuel (Jatropha, sugar cane) and vegetable crops, shipped directly to the investor countries (e.g. rice). And once the competitor gets hold of the land, it then controls the water as well, as is especially the case in irrigated areas. Private investors will only commit if their water supply is assured. The signing of formal contracts with the state guarantees them privileged access.

### *Land management policies and governance*

As land becomes less and less available, competition for access to its resources becomes increasingly tougher, leading to more attempts at land appropriation. Land legislation is directly based on western origins. It is more suited to the needs of sedentary activities such as cultivation rather than to mobile activities like pastoralism, which is difficult to define in relation to individually appropriated space. Most of the legislation currently in force in the Sahel is very ambiguous about the status of pastoral lands. Recognition of traditional rights to pasture is already well established, yet remains the exception rather than the rule in an agricultural setting. Pastoralism is not generally seen as an effective means for improving farmland in the same way that cultivation is. As a result, rights on pastoral lands generally remain precarious and not recognized by institutions (HLPE, 2011b), especially in the strategic areas of lowlands, riverbanks, wet valleys, forestry and pastoral reserves. Sustainable use of rangelands for organized pastoral groups has been attempted on several occasions, notably through “pastoral units”. These, however, were one-off measures with very mixed results.



**Figure 10. Delimitation of pastoral and agro-pastoral land use in the rural community of Ross-Béthio in northern Senegal**

Source: Diop *et al.* (2001)

Today, institutional environment is moving rapidly. In the context of the democratization movements dating from the 1990s, the Sahelian countries have initiated decentralization policies to build and strengthen forms of local governance expected to be more democratic and participative. The creation or strengthening of local governments endowed with elected councils, legal personality and proper resources has radically changed the institutional landscape and governance at the central and local levels. Admittedly, modern land-use and land-tenure regulations can appear confusing in their local application, especially where collective land management is necessary. The law of the state sometimes bumps up against traditional rules (rights of new arrivals, user rights) and local practices for resolving conflict. But these new stakeholders, communes, local governments and inter-regional authorities are gaining more and more power for managing their lands and resources. They are mandated to set up modes of governance in accordance with the current laws and regulations, while at the same time taking into account local conventions and customs. They are in charge of organizing their territory between activities (livestock, cultivation, fishing, forestry, national parks, habitats); they can intervene with the support of competent advisers in procedures of land allocation (land titles, leasing); and they can be called upon to resolve conflicts. Senegal was a pioneer in this respect and is today relatively advanced, particularly among the rural communities of the Senegal River Valley where land-use planning has been integrated in local governance processes (Figure 10).

These policies, nevertheless, remain difficult to fully implement on a large scale. Depending on the country, decentralization is more or less complete. And, despite all the promises of decentralization, it has not fully restored control over land management and natural resources to the relevant actors. Livestock farmers are still often left behind these land management processes as they are not enough self-organized. The risk for them to lose control and access to strategic resources (pastures, water) is still high. Bearing in mind the allocation of considerable chunks of land to agro-business (see above), the risk of the state taking back control is a very real one. Furthermore, the juridical model must be concurrently legitimized by the people and sanctioned by the state.

### **Sanitary risks**

Sanitary risks for livestock in the Sahel mostly belong to history, thanks to epizootic control. Many efforts have been made in the past decades in vaccination (rinderpest, pleuropneumoniae, anthrax, small ruminant pest, etc.) and tick-borne disease control with veterinary services and research. For livestock herders, risks are usually managed through control of livestock entry into the herd, water point control and the use of local medicine or even vaccines (pleuropneumoniae). Nowadays, rinderpest is officially eradicated in the world and most other epizootics are quite under control. Nevertheless, production losses owing to health constraints of livestock in the Sahel remain high, especially for young animals (infectious diseases, parasites, nutritional deficits) where environmental, feed and sanitary factors combine to result in high mortality rates (around 20 percent usually; Tyc, 1994; Ezanno, Ickowicz and Lancelot, 2005). These risks for young livestock might be one of the major foci to improve productivity and risk management through participatory approaches between herders and scientists. Other sanitary risks related to climate change in the Sahel are today very complex to estimate (Thornton *et al.*, 2009).

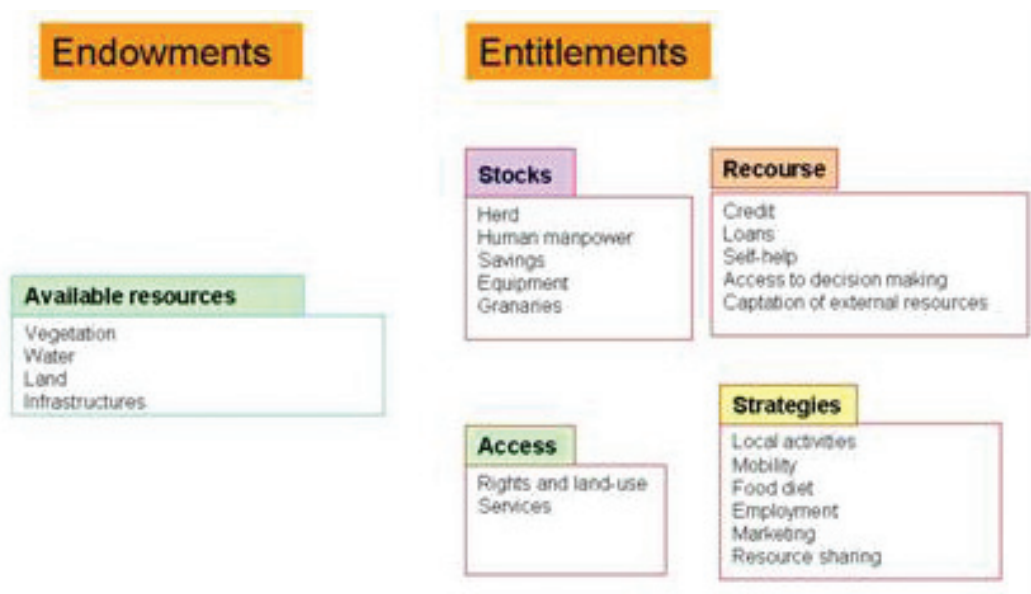
## **VULNERABILITY AND ADAPTATION STRATEGIES OF CROP-LIVESTOCK SYSTEMS**

### **A proposition for a model of vulnerability applied to crop-livestock systems**

Considering the main risks faced by crop–livestock production systems in the Sahel described in the previous sections, we propose here an adapted model of vulnerability for these systems (Figure 11). It has been built considering important literature on inequality and vulnerability applied here to poor populations in rural environments (Sen, 1981; Swift, 1989). The major modification to the model consisted of taking into account the tight integration of social and biophysical factors that play major roles for vulnerability of crop–livestock systems. This vulnerability is then not only an exposure to different types of risks that affect endowments but also a function of capabilities to react or anticipate, through entitlements owing mainly to social, demographic, and economic attributes and positions. Dealing with those risks is also fully integrated in the normal life of these people considering their highly variable environment (Chambers, 1990; Van Dijk, 1997; Bovin, 2000).

### **Adaptation strategies**

The food security of the sub-Saharan rural population relies on its capacity for making productive investments, stocks and recourses (Swift, 1989). In the case of pastoralism and



**Figure 11. Model of vulnerability proposed for crop-livestock systems**

Source: Ancey *et al.* (2009)

agro-pastoralism in arid areas, where natural resources are uncertain and scattered, herd mobility is central to these strategies. Furthermore, many studies (Khazanov, 1984; Kerven, 1992) have demonstrated the technical need of pastoralists to exchange with the outside world and have flexibility in their use of markets.

There is little comparative analysis concerning the rural exodus of pastoralists and farmers. From one generation to another, pastoralists should benefit from the numerical growth of herds, contrarily to farmers that from generation to generation are exposed to the family land division. In addition, livestock have a constant need for labour, as opposed to agriculture, which shows seasonal peaks of work. Aside from this, mobility allows pastoralists to avoid the local droughts. Finally, extensive livestock familial economy might not be as exposed to external shocks (volatility of world prices, etc.) as the export-oriented agricultural sector has been (HLPE, 2011a). These structures and strategies contribute to the hypothesis that pastoral resilience is greater than agricultural resilience.

The agreements regulating the access to resources (land, water, pasture), the productive strategies managing labour and livestock, the use of local mutual assistance networks of funding and transfers, evolve and form different resilience profiles in these production systems (Manoli *et al.*, 2010).

This latter work carried out in Ferlo (Senegal), in 2009<sup>3</sup>, helped to identify four main resilience strategies depending on the context and wealth of producers:

- The large producers of cattle and small ruminants manage their income, their relationship networks, their frequent moves, and their information. They often innovate their

<sup>3</sup> ANR research project “Contribution of livestock to the reduction of rural population vulnerability and to the promotion of their adaptability to climate and society changes in Sub-Saharan Africa” (ANR-ECLIS), 2009–2012.



farming practices and their other activities: cattle trade, diversification creating value-added, wage earning. Their resources are not exclusively local.

- A second group of wealthy livestock producers invest mainly on the income from herds and devote their work to herd maintenance and herd enlargement.
- The poorer livestock producers secure their way of life by diversification in small activities, which forms the basis of their survival. Trade activities by women outside the camp are essential.
- Finally, other poor livestock producers rely mainly on social networks and social support; particularly the mutual sharing of human resources and herds to allow their transhumance.

A survey conducted in the north of the Niger, in 2006, about the food crisis in pastoral regions, reveals that migration networks contribute to resilience, identifying three main ones (Ancy, 2006):

- Between the north of the Niger, the south of Algeria (Tamanrasset) and of Libya, migration networks and smuggling circuits allow migrants to find a job quickly and to send money to their families in the Niger. These same networks supply the shops and markets in northern Niger with Algerian and Libyan food (pasta or “maca”, sugar, etc.) and basic products.
- In some villages in the Niger, in more southern agricultural areas, the exodus, which is an integral part of the functioning of pastoral and agro-pastoral systems, goes towards villages in the south neighbouring countries, up to the markets of the coastal cities (Lome, Malinville, Abidjan, Lagos, etc.). Relocation represents a strategic part of the family’s income. But new destinations appear, especially towards Cameroon and Gabon, and in a crisis situation precipitated departures increase, without any certainty of integrating a successful network. In these cases, relocations are almost non-existent.
- Finally, other flows drain people to the capital, Niamey, mainly those without access to means of production, who have lost their herd or conceded their land. Isolated individuals try to help their rural families, but this migration to survive does not create money transfers while also sustaining an entire family in town.

These examples of migration from remote pastoral areas inside the subregion show the geographical diversity and the unequal capacity of migration networks to transfer funds from marginal and occasional assistance up to structural transfers, crucial to rural households’ survival. But in a crisis situation, challenges appear, as migrants do not integrate efficient established networks (informal social protection); on the contrary, they face more and more risks, and travel further distances with a growing uncertainty.

In all cases, these systems are generally associated with low levels of human development: infrastructure and public services are defective, especially in pastoral areas; the resilience of families relies firstly and mainly on two pillars, for which they are on their own: mobility and diversification of activities. In Ferlo (northeast of Senegal), in 2009 and 2010, as well as in the Niger, in 2005, these resilience strategies ensured the survival of livestock and households.

Nevertheless, we should pay attention to networks and strategies of human mobility; herd mobility has been well documented (rationale, conditions, distance, etc.) and may



hide that herders were sometimes forced migrants (Boutrais, 1999; Kerven, 1992) and that nowadays other migrations are to some extent a way to increase resilience of vulnerable systems. These networks and roads of migration towards saharian countries (Algeria, Libya), southern agricultural areas in Sahelian countries (Mali, Burkina, the Niger) or foreign regional countries (Cameroon, Central African Rep., Nigeria, Togo, Benin) are now facing changes and new constraints (such as civil wars, insecurity) in the whole region, raising new challenge for migrants in the search for work and remittances.

### Proposed indicators for vulnerability assessment of crop–livestock systems in the Sahel

From the model of vulnerability proposed for crop–livestock systems and the knowledge on adaptation strategies presented above, it is possible to identify indicators that would allow anticipation of the capabilities of crop–livestock systems to cope with the major risks faced in the Sahel.

Considering the four main types of risks described in this paper, ongoing research work on livestock systems' vulnerability in West Africa (Hiernaux *et al.*, 2010) suggests analysing the capabilities and potential response to crisis at different levels of organization: the national or agro-ecological zone level, the rural community level, the village or pastoral unit level and finally the family or farm level. We shall give here a few examples of these indicators to illustrate for each of the four types of risks what might be used as indicators for vulnerability assessment.

Indicators proposed in these tables are not exhaustive and still need more in-depth analysis and validation but they illustrate some important issues:

- Response to crisis and risk management for vulnerable populations are multiscale and multistakeholder matters. It needs a participatory and collaborative approach at different levels of organization including farmers, local stakeholders, politics, private sector, etc.
- Some indicators of vulnerability are shared between different types of risk (mobility, diversification of revenues, access to resources, etc.) but others are relevant to a specific risk (i.e. water availability for climatic risks; soil fertility for land tenure risks).

#### *Indicators of vulnerability to climate-related risks for crop–livestock systems*

Level of analysis	National or agro-ecological zone	Rural community	Village or pastoral unit	Family or farm
Indicators of vulnerability to climatic risks	Water availability in time and space	Water infrastructure	Access to water	Type of mobility
	Vegetation and animal biodiversity		Payment for water	Livestock and food sales
	Natural biomass availability	(Not specific)	Forage stocks	Herd size and cultivated area/size family
	Relative cropping areas related to population		Mobility ratio	Livestock feeding practices Available labour
	Pest distribution		Food stocks	Diversity of income

*Indicators of vulnerability to economic risks for crop–livestock systems*

Level of analysis	National or agro-ecological zone	Rural community	Village or pastoral unit	Family or farm
Indicators of vulnerability to economic risks	(Not specific) Available financial services: insurance, credit, grants Revenue structure	(Not specific)	Sales structure modification Terms of trade Low food diversity Market distance Market dynamics and access Access to information on markets Unusual mobility	Diversity of products High-value products Decreased number of daily meals Use of high-quality inputs Integration in value chain Self-consumption level Diversity of income

*Indicators of vulnerability to land tenure risks for crop–livestock systems*

Level of analysis	National or agro-ecological zone	Rural community	Village or pastoral unit	Family or farm
Indicators of vulnerability to land tenure risks	Relative area for livestock, forest and crop farming Water point density Irregular mobility Soil fertility decrease Water and carbon cycles Regulation and legislation texts	Demographic pressure Collective management of regulations Local associations' dynamics Frequency of conflicts Integration of all stakeholders in decision processes Land appropriation Land-use planning	Management plan Water and other resources and input pricing related to type of users Stakeholders representation Pressure on natural resources and soil degradation Low livestock and crop productivity Watering time Unusual mobility	Date of settlement Mobility type Demographic structure of family Access to resources Distance of farm to resources and services Local status Land tenure and rights

*Indicators of vulnerability to sanitary risks*

Level of analysis	National or agro-ecological zone	Rural community	Village or pastoral unit	Family or farm
Indicators of vulnerability to sanitary risks	Disease prevalence for humans, livestock and crops Quantity of discarded products Decrease in quality of products Veterinary services	(Not specific)	Disease prevalence for humans, livestock and crops Level of productivity and losses Sales ratio Access to sanitary services	Use of non-official sanitary products Food and feed shortage Herd structure Use of sanitary services

- The identification of indicators needs to be based on knowledge about farmers' strategies to cope with risks but also on a whole participatory process among scientists, farmers and policy decision-makers. This process is necessary to get relevant indicators and to build a comprehensive analysis of rural vulnerability and the way agricultural systems cope with risks and adapt their production system to changes.

## **OPTIONS TO ENHANCE ADAPTATION STRATEGIES OF CROP-LIVESTOCK SYSTEMS**

### **Integrated policies to develop crop-livestock systems able to cope with various risks**

As developed in previous parts of this document, enhancing resilience of crop-livestock systems means to increase the capacities of farmers to adapt to different types of shocks (climatic, but also economic, sanitary and related to land and demographic pressure) that have been part of their life for decades. Analysis of their strategies to cope with these events shows a number of strategies and securization systems (mobility, diversification of activities and incomes, food security, intensification, collective management, share of resource etc.) that involve not only their own capacities, ideas and skills but also the resources (biophysical, human, institutional, economic, etc.) present in their environment at different spatial scales (village, rural community, regional or national). As a consequence, a global, integrated and multiscale approach is necessary to build appropriate policies to enhance resilience and food security in crop-livestock systems.

The policy context is recognized as a major factor for enhancing the adaptation capacity of farmers to their changing environment (Steinfeld *et al.*, 2010). This underlines the need to better understand the institutional environment of crop-livestock systems, and to better assess the priorities for regional, national and local policy options.

In the following sections, we highlight three main dimensions and building blocks of integrated strategies for the resilience of crop-livestock systems, where capitalization, food security, livelihoods and market production could be objectives jointly pursued, with specific priorities according to national and local contexts.

### ***Land tenure dimension***

The land tenure policy debate in arid and subarid areas leads to at least two sets of representations.

The first set of representations is one of conflicts of property rights, according to private interests (individual or collective on several bases: household, village, ethnic group, etc.), which may be complementary, concurrent or opposite. Recent developments in the field of rangeland management suggest the need for more flexible strategies for natural resource use (Behnke, Scoones and Kerven, 1993); the analysis of risk suggests that multiple property regimes provide optimal settings for farmers and pastoralists (Van den Brink, Bromley and Chavas, 1995). From this point of view, the main challenge for land tenure policy in arid areas is to implement rights and processes in order to secure pastoral mobility in a peaceful context. Many assessments and some strategic and operational options have been provided by scientists and experts whose key words were: rules, laws, decentralization, self-management empowerment, external and local investments, cattle and village water

supply, transhumance trails (Swift, 1989; and others). Land tenure policy is part of this chain, according to the hypothesis that accurate and well implemented rights and technical investments will provide security and welfare for people, entitling them to manage rangeland and preserve ecosystems.

Another set of representations of the land tenure policy options looks at the development of arid areas, not as a compromise of rights, or a chain of negotiations, investments and entitlements, but as a common good – and points out a geopolitical stake in Saharian margins (Sahel). The preservation and “valuation” of pastoral resources, and the promotion of household welfare (meaning a better standard of living, according to their choice of livelihood, which opens another huge field of questions), are part of the rural regions’ development process in sub-Saharan Africa. For these many regions caught in a poverty trap, “solutions will have to come from contextualized policy interventions at the country level, as well as from initiatives capable of bringing about stronger regional integration (...). To insure that rural demand is met with an adequate supply of goods and services, governments must support local investments through adequate provision of public goods” (Losch, Fréguin-Gresh and White, 2011).

This represents land tenure as part of local integrated development policy. It underlines that, in case of dilemma, the economic transition should prevail over livelihood preservation.

The challenge for land tenure policy, in arid areas inhabited by pastoral populations both adapted to their environment but in need for better standard of living, facing structural constraints and changes, is then to consider, conciliate or make a choice between these two options.

### ***Governance dimension***

A public policy might be viewed as a programme of action mainly driven by the state or by its government. In that conception, a public policy is a system of regulatory measures, laws and funding priorities concerning a given topic promulgated by a governmental entity or its representatives. This vertical approach, however, does not allow an understanding of the importance of multilevel and pluri-actors’ decision processes that characterize the institutional environment of crop–livestock farming (Losch, 2008). For that reason, we will rather consider the public policy as “*normative structures that shape the actions of individual and collective actors, as well as organization*” (Lascoumes and Le Galès, 2007). In that conception, policy options will refer to multilevel governance, i.e. to individuals in interaction, exchanges, coordination mechanisms, group building, norms and conflicts.

### *The regional integration process*

Regional economic and political integration has strongly affected the macro-economic context, infrastructure and overall agricultural policies in the Sahel. The constitution of the West African Economic and Monetary Union (WAEMU) single market and, more recently, of the Economic Community of West African States (ECOWAS) zone have been two major events in this regional integration (Hugon, 2003).

The West African regional policies have resulted in monetary stability, development of infrastructure and external economic liberalization. The region as a whole signed several free trade agreements with other partner countries, such as the Economic Partnership Agreements (EPA) between ECOWAS and the European Union. This external liberalization has strongly increased the competition of imports on domestic markets in the region. In the short run, this has contributed to a slight decrease in the share of local agriculture in the provision of agro-food products to the growing urban markets (Gret-Iram, 2008). In reaction, West African countries have revised their External Common Tariff (ECT) towards the definition of a list of “sensitive” products that need to be more carefully protected.

The regional integration dynamic has also provided an opportunity to define common agricultural policies (CAP) that have resulted in putting rural development issues as a priority on the political agenda.

#### *National sectoral policies focusing on modern agriculture*

The Sahelian countries are very diverse and encompass a wide variety of national sectoral policies that are being implemented. However, most of those national policies have been shaped in the context of the domestic liberalization programmes that started in the late 1980s. Therefore, most of sectoral agricultural policies give priority to state withdrawal, to free market processes and to the promotion of commercial agriculture and agro-business. In that context, family agriculture has been undergoing a deep agrarian transition with very low support from governments (Engelhard, 2000; Losch, 2008). Except in some selected value chains (such as cotton, or irrigated rice), most of the national programmes offer relatively weak agricultural services, and rely more and more on private professional organization to manage collective actions. Poor access to seeds, to fertilizers, to credit, to capacity building and to reliable outlets are therefore key institutional constraints to the adaptation of crop-livestock systems to their changing environment (Duteurtre, Faye and Dieye, 2009).

In the context of high volatility of international prices, most West African countries decided to adopt specific “ad hoc” measures related to trade barriers, import taxes and domestic prices regulations in order to tackle food security. But the policy options that resulted from those “food crises” have revealed that consumers’ interests were sometimes more important than those of smallholder producers in the policy decision processes (Corniaux *et al.*, 2011).

#### *Local policies: actors networks and international aid*

The third level of policy governance is related to local policies conducted at small-scale territorial levels. These have been strongly influenced by local environmental and economic conditions, traditional social structures and recent decentralization policies. Therefore, it is very difficult to generalize the wide diversity of situations encountered in the whole Sahel.

Local governance in the Sahel might, however, show a set of constant characteristics that refer to the importance of local networks dynamics, local rules for accessing natural resources, and international aid (Watts, 1987; Magrin, 2007; Touré, 2010). One of the striking issues for policy options in this context is the impact of development programmes

on the empowerment of local stakeholders and on local governance. Food aid programmes, in particular, constitute crucial safety nets for mixed crop–livestock systems in the Sahel, but they might also result in de-structuring local policy networks and creating social inequities (Barret, 2003). Another issue of local governance is to evaluate to what extent local development projects might support local planning in order to foster the setting of market infrastructures, credit schemes, capacity building or agricultural services that fit the local development priorities (Magrin, 2007).

In this context of multiscale and multistakeholders' governance processes, each future policy option will need to be defined in coherence with the others. Greater participation of farmers' organizations in the governance process is also likely to increase the impact of those policy options on the adaptive capacity of rural communities, and on the resilience of the very diverse mixed crop–livestock production systems.

### ***Technical dimension***

At the farmer scale, a number of biotechnical options might help to enhance adaptation capabilities and food security. We shall propose here some options organized in three categories: adapted information tools, agro-ecological intensification, and innovation in production systems.

#### *Adapted information tools to enhance anticipation*

To allow farmers, stakeholders and politics to anticipate and manage crisis and to adapt to short- and long-term changes, it is necessary to improve availability, circulation and quality of various kinds of information. In various domains such as resource availability (rainfall, vegetation, water, livestock population, etc.), marketing (food and livestock prices in markets), sanitary and disease status (livestock, crops, food, human, etc.), services and regulations, the lack, inaccuracy or irrelevance of information is a serious constraint. Much input has to be developed in that way. However, a number of information systems and early warning systems (resources, markets, health) have already been proposed, many of them using high technologies. But due to inappropriate forms of information to final stakeholders, high running costs, poor quality or relevance of indicators used, most of these information systems are poorly efficient. Whereas early warning systems for food security in cropping regions relying on sedentary people and some market information systems are today efficient, there is still a lack of an operational information system adapted to crop–livestock systems. Some efforts are in course through collaboration between FAO, CILSS countries and institutions, and show how important the participatory process is between all stakeholders in building an appropriate and operational information system where each of the partners can contribute and share knowledge and resources (Van Dijk 1997; Ickowicz *et al.*, 2005; Ancey *et al.*, 2009; Touré *et al.*, 2009; Wane, 2010).

#### *Agro-ecological intensification*

Another option at farm level to enhance adaptation capacities and food security in the Sahel is to improve production while preserving ecosystems and the environment. In the Sahel, ecosystems have a low productivity (low and irregular rainfall, poor soils) and are



very sensitive to inappropriate management that leads to degradation of ecosystems and desertification. The new concepts of agro-ecology and ecological intensification (Cassman, 1999 in Bonny, 2011; Griffon, 2006) propose a change in paradigm for agriculture, trying to combine increase in food production together with better and sustainable functioning and management of ecosystems. For crop–livestock systems, the meaning and consequences of ecological intensification are investigated in current research<sup>4</sup>. Low level of intensification adjusted to seasonal and annual variability and ecosystem potential and services is combined with intensive use of local knowledge on natural resources and livestock needs, through straight links between social organization and animal production experts. Technical options for better integration of crop and livestock production to improve soil fertility and to reduce, through prevention practices, production losses due to diseases, pests and bad conservation of stocks, have been investigated in the last decades but need to be improved. Moreover, ecological intensification might also reduce GHG emissions, which in these types of livestock systems (livestock only grazing systems, rainfed mixed crop–livestock systems) are mainly due to poor feed diet with high fibre content. Indeed, the global impact of crop–livestock systems on the ecosystems and the environment are still debated owing to the lack of local accurate data (specific local emission factor for GHG depending on ruminant diet variability; actual volume of carbon sequestration in wide Sahelian rangelands), and there is a need for a better estimate of those impacts (carbon sequestration, biodiversity impacts, GHG emissions, water cycle).

### *System innovation*

As described in the introduction of this paper, most of crop–livestock systems rely on the mobility of the livestock system for livestock grazing systems in arid and semi-arid zones and rainfed mixed crop–livestock systems and some of them for the irrigated mixed crop–livestock systems. Whereas mobility is nowadays recognized as a relevant adaptation to variable environment, changes due to economic, environmental and social factors at local and global levels induce rapid changes in livestock systems worldwide (Gibon and Ickowicz, 2010). Diversification of activities of livestock farmers in agricultural or non-agricultural work, change in mobility regimes (part of family and of the herd), reorganization of the labour force, change in livestock species composition of the herd, decrease or increase in specialization of production, reduced interactions between livestock and crop farmers are some of the main trends observed in rural areas in the Sahel (Vall, Dugué and Blanchard, 2006; Manoli *et al.*, 2010). These changes seem to be driven by food security goals at short- and mid-term time scales but there is no evidence that these trends are sustainable for human societies and ecosystems. At farm level, these innovative systems will have to respond to the double challenge of mitigating environmental impact and taking care of limited resources, leading to the need for better efficiency in resource use. But, at a more regional or national level, there is a real need to globally assess the impacts of these changes in terms of ecological, social and economic effects and to build and think

<sup>4</sup> Agence Nationale pour la Recherche (France) research project “The interactions livestock – local development and the dynamics of the ecological intensification” – Mouve, 2011–2014

innovative systems through a participative approach among farmers, local and national policy-makers and scientists.

## CONCLUSION

Crop–livestock production systems in the Sahel have been adapting their practices and way of life for decades to various risks: climatic variability, economic risks and livestock diseases. To cope with shocks and crisis but also to support changes, they have developed various strategies based on the mobility of livestock and/or families, reorganization and diversification of activities, reciprocity and social networks. These strategies have allowed them to reproduce their societies through several major political events and droughts in the Sahel. Nowadays, climate change combined with other major factors (demographic growth, market globalization, decentralization, security issues) puts more pressure on their societies as their strategies might be not sufficient to deal with those global changes on their own and to preserve their food security. Present Sahelian policies oriented towards more regional and domestic economic liberalization leading to more competition for land and other resources are unfavourable for smallholders' crop–livestock systems. There is an important risk in that process that they will lose their adaptive capacities to changes and crisis, being more exposed to present risks (extreme climatic events, economic and market crises) and finally jeopardizing millions of people, millions of livestock and millions of hectares of natural resources.

In this paper, we have shown how marketing policies, land tenure and land-use management and regulations, investments in infrastructures and services are main priorities to enhance the capability of crop–livestock systems to adapt to the recent changes. Synergies between policy-makers, livestock experts and crop–livestock systems' farmers in the definition of strategies and policies at different levels (regional, national, local) are needed to define proper ways of development in this area. In the context of Sahelian countries, to respond to the growing demand in animal products, a combination of industrial or semi-industrial livestock systems together with smallholder livestock systems will allow the provision of more products, appreciation of the value of large areas of rangeland resources and the preservation of livelihoods for nearly 60 percent of the Sahelian human population. Taking into account the rapid changes in global and regional markets and in demographic pressures on land, it is timely to define economic policies and land-use policies from the regional to the local levels and in a participatory multistakeholder approach to take into account national as well as local livestock development issues. These policies would have to consider, on one hand, how to enhance adaptation strategies of crop–livestock systems (mobility, diversification, access to infrastructures and services, education) that will allow the improvement of production, livelihoods and social status of millions of people who own millions of livestock and to optimize the use of huge amounts of natural resources of rangelands and crop by-products. On the other hand, these policies would have to offer opportunities for entrepreneurs to develop more intensive and complementary livestock systems (milk, meat) to value other local resources when available (agricultural products or by-products, water, arable land, etc.) in an affordable, economical and institutional context (price policies, import taxes, technical services, transport infrastructures, etc.).

## REFERENCES

- AFD (Agence Française de Développement). 2007. Analyse rétrospective de la crise alimentaire au Niger en 2005. LASDEL.
- Ancey, V. 2006. *Évaluation de la réponse du PAM à la crise alimentaire au Niger en 2005. Note 4 : Caractérisation de la crise pastorale*. [S.l.] : s.n., 10 p.
- Ancey, V., Ickowicz, A., Corniaux, C., Manoli, C. & Magani, S. 2008. Stratégies pastorales de sécurisation chez les Peuls du Ferlo (Sénégal). *Journal des africanistes*, 78(1-2): 105-119 (available at <http://africanistes.revues.org/2280>).
- Ancey, V., Ickowicz, A., Touré, I., Wane, A. & Diop, A.T. 2009. La vulnérabilité pastorale au Sahel: portée et limites des systèmes d'alerte basés sur des indicateurs. In G. Duteurtre & B. Faye, eds. *L'élevage, richesse des pauvres : Stratégies d'éleveurs et organisations sociales face aux risques dans les pays du Sud*. pp. 117-132. Versailles, France, Ed. Quae.
- Assani, B., Diop, A.T., Touré, I. & Wane, A. 2011. Crise des marchés mondiaux et nationaux des aliments de bétail – Adaptation organisationnelle des pasteurs du Ferlo (Sénégal). In P. Pillon, Coord. *La question alimentaire sénégalaise dans la mondialisation*. Projet d'ouvrage. Paris, L'Harmattan. 8 p.
- Bah, A., Toure, I., Fourage, C., Gaye, D. I., Leclerc, G., Soumare, M.A., Ickowicz, A. & Diop, A.T. 2010. Un modèle multi-agents pour étudier les politiques d'affectation des terres et leurs impacts sur les dynamiques pastorales et territoriales au Ferlo (Sénégal). *Cah. Agric.*, 19(2): 118-126.
- Baier, S. 1980. *An economic history of Central Niger*. Oxford, UK, Clarendon Press.
- Barret, C.B. 2003. Rural poverty dynamics: development policy implications. *Agricultural Economics*, 32: 45-60.
- Bégué, A., Vintrou, E., Ruelland, D., Claden, M. & Dessay, N. 2011. Can a 25-year trend in vegetation dynamics (NOAA-AVHRR NDVI) be interpreted in terms of land use change? A case study of the Bani catchment in Mali. *Global Environmental Change*, 21(2): 413-420. Doi: 10.1016/j.gloenvcha.2011.02.002.
- Behnke, R.H., Scoones, I. & Kerven, C. 1993. *Range ecology at disequilibrium*. London, Overseas Development Institute, International Institute for Environment and Development. 248 p.
- Bonfiglioli, A.M. 1988. *Dudal : histoire de famille et histoire de troupeau chez un groupe de WoDaaBe du Niger*. Cambridge, UK, Cambridge University Press.
- Bonfiglioli, A.M. 1990. Pastoralisme, agro-pastoralisme et retour : itinéraires sahéliens, in Sociétés pastorales et développement. *Cahiers des sciences humaines*, 26. Éditions ORSTOM.
- Bonnet, B., Banzhaf, M., Giraud, P-N. & Mahamat, I. 2004. *Analyse des impacts économiques, sociaux et environnementaux des projets d'hydraulique pastorale financés par l'AFD au Tchad*. Agence Française de Développement (AFD)-IRAM. 229 p.
- Bonny, S. 2011. L'agriculture écologiquement intensive: nature et défis. *Cahiers Agricultures*, 20(6): 451-462.
- Bovin, M. 2000. Pastoralists manoeuvring in the drought-ridden Sahel. In B. Berner & P. Trulsson, eds. *Manoeuvring in an environment of uncertainty: structural change and social action in sub-Saharan Africa*, pp. 233-262. Farnham, UK, Ashgate.
- Boutrais, J. 1999. Les éleveurs, une catégorie oubliée de migrants forcés. In V. Lassailly-Jacob, J-Y. Marchal & A. Quesnel, eds. *Déplacés et réfugiés : la mobilité sous contrainte*, pp. 161-192. Paris, Institut de recherche pour le développement.

- Cassman, K.G.** 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. USA*, 96: 5952–5959.
- Chambers, R.** 1990. Editorial introduction: vulnerability, coping, and policy. *IDS Bulletin*, 20(2): 1–7.
- Corniaux C., Dia, D., Diao-Camara, A. & Duteurtre, G.** 2011. Les importations laitières : vraie question ou faux problème ? Le lait comme révélateur des enjeux du développement agricole au Sénégal, dans un contexte de mondialisation. In P. Pillon, Dir. *La faim par le marché : aspects sénégalais de la mondialisation*, pp. 219\_238. Paris, L'Harmattan.
- David-Benz H., Diallo A., Lançon F., Meuriot V., Rasolofo P., Temple L. & Wane A.** 2010. L'imparfaite transmission des prix mondiaux aux marchés agricoles d'Afrique subsaharienne. Rapport pour la Fondation FARM. Paris. 99 p.
- Dietvorst, D. & Kerven, C.** 1992. The pastoral Fulani of Niger. In C. Kerven. *Customary commerce: a historical reassessment of pastoral livestock marketing in Africa*. London, Overseas Development Institute.
- Diop, B., d'Aquino, P., Corniaux, C. & Camara, S.** 2001. La gestion des parcours pastoraux en systèmes irrigués : cas de la Communauté Rurale de Ross Béthio, Région de St Louis – Sénégal. In E. Tielkes, E. Schlecht & P. Hiernaux, eds. *Elevage et gestion de parcours au Sahel, implications pour le développement*, pp. 201–208. Atelier Régional sur Les approches de la gestion des pâturages et les projets de développement : quelles perspectives ?, Niamey, Niger, 2–6 October 2000.
- Dupire, M.** 1962. Trade and markets in the economy of the nomadic Fulani of Niger (Bororo). In P. Bohannan & G. Dalton, eds. *Markets in Africa*. Chicago, USA, Northwestern University Press.
- Duteurtre, G., Faye, M.D. & Dieye, P.N., Dir.** 2009. *L'agriculture sénégalaise à l'épreuve du marché*. Paris, Karthala. 451 p.
- ECOWAS.** 2005. Atlas régional des transports et des télécommunications dans la CEDEAO. CEDEAO. 40 p.
- Engelhard, P.** 2000. *L'Afrique : plaidoyer pour une nouvelle économie*. Dakar, Enda éditions. 239 p.
- Ezanno, P., Ickowicz, A. & Lancelot, R.** 2005. Relationships between N'Dama cow body condition score and production performance under an extensive range management system in Southern Senegal: calf weight gain, milk production, probability of pregnancy, and juvenile mortality. *Livestock Production Science*, 92: 291–306.
- FAO.** 2006. *Livestock's long shadow: environmental issues and options*, by H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan. Rome. 390 p.
- FAO.** 2008. *La flambée des prix des denrées alimentaires : faits, perspectives, effets et actions requises*. Conférence de Haut Niveau sur La Sécurité Alimentaire Mondiale : Les Défis du Changement Climatique et des Bioénergies. Rome, du 3 au 5 juin 2008.
- FAO/OECD, coordinators.** 2011. *Price volatility in food and agricultural markets: policy responses*. Rome, FAO, IFAD, IMF, OECD, UNCTAD, WFP, World Bank, WTO, IFPRI and UN HLTF.
- Fernandez-Rivera S., Okike, O., Manyong, V., Kruska, R., Williams, T.O. & Tarawali, S.** 2004. Classification and description of the major farming systems incorporating ruminant livestock in West Africa. In T.O. Williams, S. Tarawali, P. Hiernaux & S. Fernandez-Rivera, eds. *Sustainable crop-livestock production for improved livelihoods and natural resource management in West Africa*, pp. 89–122. Proceedings of an international conference held at IITA, Ibadan, Nigeria, 19–22 November 2001. Wageningen, Netherlands, CTA and APC-EC, and Nairobi, Kenya, ILRI.

- Gibon, A. & Ickowicz, A., eds. 2010. Transformation des systèmes d'élevage extensifs dans les territoires ruraux. *Numéro thématique Cahiers Agricultures*, 19(2): 77–172 (available at [http://www.cahiersagricultures.fr/archives/sommaire.phtml?cle\\_parution=3315](http://www.cahiersagricultures.fr/archives/sommaire.phtml?cle_parution=3315)).
- Gitz, V. & Meybeck, A. 2012. *Risks, vulnerabilities and resilience in a context of climate change*. This publication.
- Gret-Iram (Groupe de recherche et d'échanges technologiques-Institut de radioastronomie millimétrique). 2008. *Etude prospective sur les mesures de protection nécessaires pour le développement du secteur agricole en Afrique de l'Ouest (illustration sur quelques filières stratégiques)*. Réseau des organisations paysannes et des producteurs de l'Afrique de l'Ouest (ROPPA). Oxfam International. 146 p.
- Griffon, M. 2006. *Nourrir la planète*. Paris, Editions Odile Jacob.
- Harder, W. & Jung, V. 2008. Pénurie de matières premières agricoles : phénomène passager ou défi à long terme ? *Revue de Politique Economique – La vie économique*, 9–14 Septembre.
- Hiernaux, P. & Soussana, J.F. 2011. Les changements climatiques et leurs impacts attendus en régions chaudes. In Actes du séminaire "Elevage et Environnement en Régions Chaudes". Point sur les controverses, Méthodologies d'étude, Pistes de recherche, pp 8–12. INRA-CIRAD, Sète 6–10 June 2011.
- Hiernaux, P., Fernandez-Rivera, S., Schlecht, E., Turner, M.D. & Williams, T.O. 1997. Livestock-mediated nutrient transfers in Sahelian agro-ecosystems. In G. Renard, A. Neef, K. Becker & M. von Oppen, eds. *Soil fertility management in West African land use systems*, pp. 339–347. Proceedings of the Regional Workshop, Niamey, Niger, 4–8 March. Weikersheim, Margraf Verlag.
- Hiernaux, P., Mougin, E., Becerra, S., Bidou, J.-E., Bonnet, B., Descroix, L., Droy, I., Ickowicz, A., Mering, C., Peugeot, C. & Wane, A. 2010. ANR Research project on "Contribution of livestock to the reduction of rural population vulnerability and to the promotion of their adaptability to climate and society changes in Sub-Saharan Africa" (ANR-ECLIS), half way through. Atelier AMMA. CNRS, Toulouse, France, 2–5 November 2010.
- HLPE. 2011a. *Price volatility and food security*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome (available at [http://www.fao.org/fileadmin/user\\_upload/hlpe/hlpe\\_documents/HLPE-price-volatility-and-food-security-report-July-2011.pdf](http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE-price-volatility-and-food-security-report-July-2011.pdf)).
- HLPE. 2011b. *Land tenure and international investments in agriculture*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome (available at [http://www.fao.org/fileadmin/user\\_upload/hlpe/hlpe\\_documents/HLPE-Land-tenure-and-international-investments-in-agriculture-2011.pdf](http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE-Land-tenure-and-international-investments-in-agriculture-2011.pdf)).
- Hugon, Ph. ed. 2003. *Les économies en développement à l'heure de la régionalisation*. Paris, Karthala. 336 p.
- Ickowicz, A., Touré, I., Ancey, V., Leclerc, G., Darly, S. & Damman, G. 2005. *Programme LEAD "Pastoralisme et environnement au Sahel" (Pesah)*. Rapport Final. FAO – CIRAD – PPZS, Rapport Cirad n° 2005-05, Montpellier. 113 p. + annexes.
- Ickowicz, A., Aminou, B.K., Ancey, V., Azoulay, G. & Benamour A. 2010. *Note de synthèse. Interventions financées par l'AFD dans le secteur de l'hydraulique pastorale au Tchad sur la période 1994-2004*. Rapport AFD-CIRAD, Montpellier. 19 p.
- IMF (International Monetary Fund). 2006. *World economic outlook financial systems and economic cycles. Chapter 5. The boom in nonfuel commodity prices: can it last?* Washington, DC.

- Janin, P. & de Suremain, C.E., eds.** 2005. La question alimentaire en Afrique : risque et politisation. *Revue Tiers Monde*, n°184, oct 2005. PUF.
- Khazanov, A.M., ed.** 1984. *Nomads and the outside world*. Cambridge, UK, Cambridge University Press.
- Kerven, C.** 1992. Customary commerce: a historical reassessment of pastoral livestock marketing in Africa. London, Overseas Development Institute
- Landais, E. & Lhoste, P.** 1993. Systèmes d'élevage et transferts de fertilité dans la zone des savanes africaines. II. Les systèmes de gestion de la fumure animale et leur insertion dans les relations entre l'élevage et l'agriculture. *Cahiers Agricultures*, 2: 9–25.
- Lascoumes, P. & Le Galès, P.** 2007. *Sociologie de l'action publique*. Paris, Armand Colin, Collection "128". 128 p.
- Lesnoff, M., Corniaux, C. & Hiernaux, P.** 2012. Sensitivity analysis of the recovery dynamics of a cattle population following drought in the Sahel region. *Ecological Modelling*, 232: 28–39.
- Losch, B.** 2008. La recherche d'une croissance agricole inclusive au coeur de la transition économique africaine. In J.C. Devèze, Dir. *Défis agricoles africains*, pp. 47–72. Paris, Karthala.
- Losch, B., Fréguin-Gresh, S. & White, E.** 2011. *Rural transformation and late developing countries in a globalizing world. A comparative analysis of rural change*. Final Report of the RuralStruc Program, Revised Version. Washington, DC, World Bank.
- Ly, C., Fall, A. & Okike, I.** 2010. West Africa. The livestock sector in need of regional strategies. In P. Gerber, H. Mooney & J. Dijkman, eds. *Livestock in a changing landscape. Vol. 2. Experience and regional perspectives*. Washington, DC, Island Press. 189 p.
- Magrin, G.** 2007. Le développement local introuvable : réflexions sur l'importation d'un concept au Sénégal. *Les Cahiers du GIRARDEL* n° 4, Actes de l'atelier, Déchets et développement local, Université Gaston Berger de Saint-Louis, pp. 32–64.
- Manlay, R.J., Ickowicz, A., Masse, D., Feller, C. & Richard, D.** 2004. Spatial carbon, nitrogen and phosphorus budget of a village of the West African savanna - II. Element flows and functioning of a mixed-farming system. *Agricultural Systems*, 79(1): 83–107.
- Manoli, C., Corniaux, C, Ickowicz, A., Moulin, C-H. & Dedieu, B.** 2010. *Entre production pour le marché et sécurisation des familles : quels rôles tient l'élevage dans le Ferlo sénégalais ? Une approche par les trajectoires sociotechniques*. In-Agir en situation d'incertitude. Ancey V., Dedieu B., Avelange I. eds scientifiques. Peter Lang édition, collection Ecolopolis. (In press).
- Meuriot, V., Lançon, F., Diallo, A., David-Benz, H., Temple, L., Rasolofo, P. & Wane, A.** 2011. Transmission des prix internationaux du riz et volatilité sur les marchés vivriers Africains : analyse et enjeux. *Revue Tiers Monde*, 23 p. (in press).
- Miehe, S, Kluge, J., Von Wehrden, H. & Retzer, V.** 2010, Long-term degradation of Sahelian rangeland detected by 27 years of field study in Senegal. *Journal of Applied Ecology*, 47: 692–700.
- Mitchell, D.** 2008. *A note on rising food prices*. Washington, DC, World Bank.
- Nubukpo, K.** 2011. *L'improvisation économique en Afrique de l'ouest. Du coton au franc Cfa*. Paris, Karthala.
- RPCA (Réseau de Prévention des Crises Alimentaires).** 2008a. *Situation alimentaire dans le Sahel et en Afrique de l'Ouest : La sécurité alimentaire des ménages les plus pauvres des milieux urbains et ruraux menacée par la hausse des prix des denrées alimentaires*. April, Note 19 (available at [www.food-security.net](http://www.food-security.net)).



- RPCA. 2008b. *Situation alimentaire dans le Sahel et en Afrique de l'Ouest : Gérer la période de soudure dans un contexte de hausse des prix des denrées alimentaires*. May, Note 20 (available at [www.food-security.net](http://www.food-security.net)).
- Robinson, T.P., Thornton, P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. & See, L. 2011. *Global livestock production systems*. Rome, FAO-ILRI. 152 p.
- Sen, A. 1981. *Poverty and famines: an essay on entitlement and deprivation*. Oxford, UK, Clarendon Press. 257 p.
- Sere, C. & Steinfeld, H. 1996. *World Livestock production systems: current status, issues and trends*. FAO Animal Production and Health Paper No. 127. Rome.
- Steinfeld, H., Mooney, H.A., Schneider, F. & Neville, L.E., eds. 2010. *Livestock in a changing landscape. Volume 1. Drivers, consequences, and responses*. Washington, DC, Island Press. 396 p.
- Sutter, J. 1982. Commercial strategies, drought and monetary pressure: WoDaaBe nomads of Tanout Arrondissement Niger. *Nomadic Peoples*, 11: 26–60.
- Sutter, J. 1987. Cattle and inequality: herd size differences and pastoral production among the Fulani of northeastern Sénégal. *Africa*, 57(2): 196–218.
- Swift, J. 1989. Why are rural people vulnerable to famine. *IDS Bulletin*, 20(2): 8–15.
- Thébaud, B. 1990. Politiques d'hydraulique pastorale et gestion de l'espace au Sahel. *Cahiers des sciences humaines, Orstom*.
- Thébaud, B. 2002. *Foncier pastoral et gestion de l'espace au Sahel. Peuls du Niger oriental et du Yagha burkinabé*. Paris, Karthala.
- Thornton, P.K., van de Steeg, J., Notenbaert, A. & Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. *Agricultural Systems*, 101: 113–127.
- Touré, O. 2010. *Etudes de cas sur la vulnérabilité et l'adaptabilité des éleveurs face aux événements dans la commune de Tessékéré au Sénégal*. Projet ANR-ECLIS. Montpellier, France, IRAM. 105 p.
- Touré, I., Ickowicz, A., Ancey, V., Akpo, L.E., Ba, A., Bah, A., Corniau, C., Diop, A.T., Diop Gaye, I., Garba, I., Leclerc, G., Ndiaye, P., Niang, I., Saley, M., Soumare, M.A., Toutain, B. & Wane, A. 2009. *Système d'information sur le pastoralisme au Sahel, phase 2*. Rapport Final, CIRAD. 53 p.
- Toutain, B. & Ickowicz, A. 1999. Grazing systems module. In K.L.I. Campbell, N.H. Hodgson & M. Gill, eds. *Livestock and environment toolbox*. CD-ROM. Livestock, Environment and Development (LEAD) Initiative. Rome, FAO. ISBN 92-5-104445-7 (available at <http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/homepage.htm>).
- Toutain, B., Ickowicz, A., Dutilly-Diane, C., Reid, R., Diop, A.T., Taneja, V.K., Gibon, A., Genin, D., Ibrahim, M., Behnke, R. & Ash, A. 2010. Impacts of extensive livestock systems on terrestrial ecosystems. In H. Steinfeld, H. Mooney, F. Schneider & L. Neville, eds. *Livestock in a changing landscape. Volume I: Drivers, consequences, and responses*, pp 165–195. SCOPE, Washington, DC, Island Press.
- Tyc, J. 1994. *Etude diagnostic sur l'exploitation et la commercialisation du bétail dans la zone dite des six forages*. Sénégal. Saint-Louis. PAPP/GTZ.
- Vall, E., Dugué, P. & Blanchard, M. 2006. Le tissage des relations agriculture-élevage au fil du coton. *Cahiers Agricultures*, 15(1): 72–79.



- Van den Brink, R., Bromley, D.W. & Chavas, J.-P.** 1995. The economics of Cain and Abel: agro-pastoral property rights in the Sahel. *The Journal of Development Studies*, 31(3): 373–399.
- Van Dijk, H.** 1997. Risk, agro-pastoral decision making and natural resource management in fulbe society, central Mali. *Nomadic Peoples*, 1(1): 108–133.
- Wane, A.** 2010. *Evaluation de la situation alimentaire et nutritionnelle des ménages pastoraux du Burkina Faso et du Mali*. Rapport d'expertise pour le Programme alimentaire mondial. 84 p.
- Wane, A., Touré, I. & Ancey, V.** 2009. Assets of the market, assets of the rural world: Pastoral market income distribution in the Senegalese Sahel (Ferlo). *Journal of Income Distribution*, 18(3–4): 232–248.
- Wane, A., Touré, I. & Ancey, V.** 2010a. Pastoralisme et recours aux marchés – Cas du Sahel sénégalais (Ferlo). *Cahiers Agricultures*, 1(1), October, 7 p.
- Wane, A., Touré, I. & Ancey, V.** 2010b. *Vulnérabilité nutritionnelle des populations pastorales du Mali et du Burkina Faso : une approche par les risques*. OCDE-CILSS : Réunion du Réseau de Prévention des Crises Alimentaires, Accra, Ghana, 12–14 December.
- Watts, M.** 1987. Drought, environment and food security: some reflections on peasants, pastoralists and commoditization in dryland west Africa. In M. Glantz, ed. *Drought and hunger in Africa. Denying famine a future*. Cambridge, UK, Cambridge University Press.