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Human Vulnerability to Climate Variability in the Sahel: Farmers' Adaptation Strategies in Northern Burkina Faso

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Abstract In this study, the authors investigate farmers' vulnerability to climate variability and evaluate local adoption of technology and farmers' perceptions of adaptation strategies to rainfall variability and policies. A survey was conducted in a community in northern Burkina Faso following the crop failure of 2004. In 2006, following a better harvest, another survey was conducted to compare farmers' actions and reactions during two contrasted rainy seasons. The results confirm that farmers from this community have substantially changed their practices during the last few decades. They have adopted a wide range of techniques that are intended to simultaneously increase crop yield and reduce yield variability. Micro water harvesting (Zaï) techniques have been widely adopted (41%), and a majority of fields have been improved with stone lines (60%). Hay (48%) and sorghum residues are increasingly stored to feed animals during the dry season, making bull and sheep fattening now a common practice. Dry season vegetable production also involves a majority of the population (60%). According to farmers, most of the new techniques have been adopted because of growing land scarcity and new market opportunities, rather than because of climate variability. Population pressure has reached a critical threshold, while land scarcity, declining soil fertility and reduced animal mobility have pushed farmers to intensify agricultural production. These techniques reduce farmers' dependency on rainfall but are still insufficient to reduce poverty and vulnerability. Thirty-nine percent of the population remains vulnerable after a good rainy season. Despite farmers' desire to remain in their own communities, migrations are likely to remain a major source of regular income and form of recourse in the event of droughts.

Keywords Smallholder farmer · Climate risk · Vulnerability · Adaptation · Sahel · Burkina Faso

Introduction

The Sahelian rural population is considered one of the most vulnerable on earth (Martineu and Tissot 1993; Lebel and Amani 1999; New and others 2000). This vulnerability is partly caused by the variability of the West African monsoon. During the 20th century, the Sahelian population has experienced several droughts with dramatic consequences (Gado 1993; Mortimore and Adams 2001). The famine of the early 1970s caused significant human and animal mortality. The drought of the mid-1980s had a smaller impact because international food aid was more substantial and arrived on time. Since then, the international community has invested large sums in the region. Numerous programs and projects have tried many different strategies to lift the population out of poverty. New agricultural techniques have been tested and promoted. Dams have been built and boreholes drilled. Schools and health centers have been built.

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The international community was surprised when the region again called for help in 2004 after the rainy season failed and a new locust invasion ravaged some regions. Why is the region still vulnerable? Have farmers adopted new cropping techniques? Is there still room to adopt more of these? What do farmers think of various policy options? Are the new instruments able to mitigate deeper crises? Are farmers and herders better prepared for future climate variability?

Two surveys were administered to a sample of Sahelian farmers from a representative community in northern Burkina Faso. Farmers' estimations of their production were used to calculate a vulnerability index calculated. Farmers' individual and group interviews helped establish their opinions regarding key techniques, policies, and adaptation strategies. The questions involved consumption, migration, food aid, technical innovations, irrigation, and policies and strategies for adaptation to new conditions.

In the first part of the study, we review some key concepts about vulnerability, food security, poverty, and adaptation strategies. We then analyze the responses to the questionnaire and adapt the calculation of a vulnerability index developed by CILSS (Comité International de Lutte contre la Sécheresse au Sahel, or International Committee to Fight Droughts in the Sahel) (CILSS 2001).

Farmers' Vulnerability and Adaptation in the Sahel

During the drought of the 70s and 80s, most Sahelian countries were pursuing a somewhat socialist agenda, in which governments played a leading role in agricultural development and aid. The policies were ineffective in dealing with the consequences of the droughts. Because indebted governments ran out of cash, the International Monetary Fund (IMF) and the World Bank managed to push a liberalization agenda under the Structural Adjustment Programs (SAP). The focus, first on macroeconomic austerity, later shifted toward poverty reduction programs. Within this poverty debate emerged the need to better understand the changes between levels of poverty. Debates about farmers' "vulnerability" and "adaptation strategies" now top the agenda of the development community. The need to clarify these concepts is reinforced by concerns about the impact of climate changes. Sahelian policy makers are now drawing mitigation plans to cope with the effect of both droughts and floods (Adger and others 2007). More recently, food and energy prices have increased dramatically, triggering a major new food crisis. Calls to help the most vulnerable are at their highest, but solutions remain divided between those asking for the removal of import and value added taxes and those seeking higher import taxes to protect local producers against the world market.

Who is Vulnerable?

Most aid plans try to target the most vulnerable regions (CILSS 2001) and the most vulnerable groups within these regions. However, aid programs do not always display clear targeting criteria (Trench and others 2007). A vulnerable individual, group, or community is likely to suffer from hunger and increasing poverty when exposed to an external shock such as a drought, flood, pest invasion, or disease (Maddison 2006; Smit and Wandel 2006). Income also drops due to job loss or the loss of migration opportunities. The most vulnerable people lack the means to build sufficient food stocks to assure a minimum food intake or to generate enough income to buy basic food and medication. The consequences of vulnerability are malnutrition, poor health (especially among children), and general psychological distress.

Why do scientists insist on investigating farmers' vulnerability? How different is it from poverty? Indeed, one can be poor without being vulnerable and vice versa. For example, small subsistence farmers in the south of Burkina Faso are considered poor but not really vulnerable to droughts. Some herders are considered rich when they own large herds, but they are vulnerable to losses from a single drought or an epidemic. Sahelian farmers and herders can fall into and get out of poverty quite rapidly. Some of this mobility can result from exogenous factors such as climate shock, price swings, or diseases, but it can also result from more permanent changes in land and water availability, factor productivity, adoption of improved technologies, or access to new market opportunities. Distinguishing structural mobility from more short-term crossing of the poverty line clarifies the factors that facilitate such structural changes (Barrett 2007).

The Causes of Population Vulnerability in the Sahel

Explanations of the causes of the Sahelians' particular vulnerability are usually grouped in two categories. The first is climate. The Sahelian climate is one of the most variable on earth. The droughts of the 1970s and 1980s are reminders that climate has an impact on poverty and people's persistent vulnerability. Since the Sahelian climate is so irregular, its inhabitants have faced strong difficulties in investing and accumulating wealth. The outlook concerning climate variability is uncertain. Some studies based on global climate model projections suggest that climate variability might aggravate the situation of African agriculture (Kurukulasuriya and others 2006). While global models disagree over future rainfalls, they all predict more variability in rainfall amount and distribution. Evaporation and plant transpiration will increase with global warming,

which will reduce crop yields unless rainfalls compensate the loss due to excessive heat.

The second most commonly cited cause of vulnerability is increasing population density with simultaneous scarcity of resources (Pieri 1989; Pieri 1992; Barbier 1998; Maire and Delpeuch 2004; Guenguant 2005). This discourse states that communities are running into Malthusian crises in which population density is too high and some carrying capacity or ecological equilibrium is exceeded. An increasing population cultivable the arable land until there is no more fallows, causing declines in soil fertility and crop yields. Because farmers do not have the means to adopt techniques to maintain this fertility, nor to intensify crop production or to feed their animals, yields remain low. Food crises tend to occur when some climate shock unveils an inherent lack of productivity (Diamond 2005).

While the pessimistic view still prevails, some researchers suggest that Sahelian farmers and herders have a much better capacity for adapting to population pressure and climate variability than previously thought. Proof of soil fertility decline is unconvincing, and yields have not declined as the pessimists predicted. When famines have struck, they have been more the result of bad policies than of local communities' incapacity to deal with new challenges (Boserup 1965; Lele and Stones 1989; Mortimore and Adams 2001). Emphasis is usually placed on local knowledge rather than external transfer of technology (Ajibade and Shokemi 2003).

Both climate irregularity and population density can be overcome. Many semi-arid countries in the world are neither poor nor vulnerable. Also, densely populated areas are often more likely to be able to sustain investment in land conservation and risk reducing techniques. However, so far, among the development pathways proposed for the Sahel, no clear winner has been identified.

What Are the Proposed Solutions?

Among the solutions proposed by aid agencies and research centers, one can distinguish the traditional "agricultural intensification pathway" based upon external input, improved seeds, mechanization, irrigation and ranching. This pathway is considered to have failed in the Sahel, since adoption of these types of techniques has remained disappointing (De Rouw 2004). Economists explain this lack of adoption by market failure. Where some factor markets (land, labor, capital, and risk) are not functioning, farmers cannot invest to respond to market signals (de Janvry and others 1991). In the Sahel, none of these markets is functioning properly. Farmers have no access to credit because they have no collateral. The absence of an effective mechanism of insurance against a variable climate makes investment too risky. The World Bank is promoting land privatization and insurance schemes, but with little impact to date.

On the ground, most development agencies have been promoting the adoption of low-cost innovations. These include soil conservation techniques, water harvesting techniques, agroforestry and crop-livestock integration, crop storage, small dams, and improved lowland. Adoption by farmers has been uneven, but some success stories have been reported, especially in Burkina Faso (Kaboré and Reij 2004; Reij and others 2005).

Farmers' Adaptation Strategies

As most solutions brought by outsiders have failed, scientists are increasingly investigating the adaptation strategies that farmers themselves have adopted over the past decades to deal with both population density and climate variability. In this context, scientists look at a broader set of activities than agriculture. Farmers are no longer pure subsistence farmers, as they are increasingly integrated into the market economy and rely increasingly on cash income to improve their well-being, including their food consumption. The concept of vulnerability now goes beyond food self-sufficiency or simple food security. One must understand farmers' diversification strategies: they need the human capital, skill, organization and connections to react adequately when production fails or when their regular source of income is reduced. Some link the concept of adaptation strategies to the concept of capabilities developed by Amartya Sen, winner of the Nobel Prize in economics (Sen 1981; Drèze and others 1995). He shows that famine can occur even when food is available because the most vulnerable segment of the population cannot access the food supply when needed. Sen was among the first to promote the replacement of direct food aid by "food for work" programs, which improve the buying power of the most vulnerable.

The general mood is that Sahelian farmers and herders are still very vulnerable and that the right instruments to reduce this vulnerability are not yet available (Trench and others 2007). More evidence is required to explore the current level of vulnerability of Sahelian farmers and to investigate farmers' diverse adaptation strategies. Despite innumerable participatory meetings with communities to prioritize their demands, it is still unclear which policies farmers favor to lift themselves out of poverty.

Methods

The present study was carried out in a typical Sahelian community in northern Burkina Faso. Several focus group discussions and two detailed surveys were carried out

among a random sample of 105 heads of farms in 2004 and 100 in 2006, taken from the total number of farms present in Tougou (340 farms). The 2004 rainy season was poor and resulted in a severe food crisis, while 2006 rainy season was considered excellent. Figure 1 shows the decadal rainfalls in Tougou itself. Yearly rainfall reached 596 mm in 2004 against 704 in 2006. Farmers also described the 2004 rainy season as too short because it halted too early when grains were not mature yet.

Production and consumption of grain were not measured but estimated by farmers themselves. Most farmers can estimate their harvest in terms of bags of 100 kg of grain even if they do not sell all of the grain. Farmers' estimates were crosschecked using local measurement methods, such as number of carts and months of grain consumption from the granaries. Most farmers do not know the size of their land. Enumerators measured one field per farm and asked farmers to evaluate the size of their other fields relative to the measured field. Some tests showed that they were able to extrapolate the size of their plots quite accurately. Estimated yields were similar to those measured in more in-depth studies conducted in Tougou (Fox and Rockström 2003) and in the Yatenga province (Matlon and Fafchamps 1988; Bagre and others 1989).

We then calculated an index of food vulnerability developed by CILSS. The index is called the Virtual Rate of Satisfaction of Grain Needs (Garavani 1997; CILSS 2001). It balances production and consumption of basic grains such as millet, sorghum, maize, and rice. It then estimates the cash income from activities such as sales of beans, peanuts, and small animals. These sales are converted into their grain equivalent using the highest purchase price during the dry season, when farmers usually buy food. CILSS uses this indicator to map the most vulnerable administrative units in the Sahel. We used this indicator at the farm level to link the impact of the two rainy seasons to farmers' vulnerability and adaptation strategies. CILSS usually does not include income from vegetable production. As this production is becoming a common adaptation strategy in the Burkinabè Sahel, we analyzed the specific contribution of vegetable production to the farms' vulnerability index.

The Study Site

The community of Tougou is part of the Yatenga province in northern Burkina, 30 km east of a large city, Ouahigouya. Tougou is comparable to other communities on the central plateau of Burkina Faso. The climate of Tougou is Sahelian, close to the isohyets 650 mm. Figure 2 shows annual rainfalls in Ouahigouya, 30 km from Tougou. Rainfall patterns over recent decades can be divided into several periods. While the 1960s were a wet period, two severe droughts occurred in the early 1970s and mid-1980s. Since the mid-1980s, rainfalls have gradually improved but have not reached the level of the 1960s. Some recent rainy seasons have still yielded less rain than the long-term average, but the 2006 and 2007 seasons were considered wetter.

The population was 3,780 in 1998 over an area of 22 km^2. Population density thus exceeds 170 inhabitants per square kilometer, a common ratio in central Burkina Faso. The reason for this high density may be found in history. The region was dominated by the powerful Mossi kingdom that provided peace for several centuries. Natural population growth is still 3% per year on the central plateau (Ouedraogo 2001). However, migrations have become important in Tougou. According to the Tougou census of 1998, there are one-third fewer adult men than women. These men have migrated mainly to the southern part of

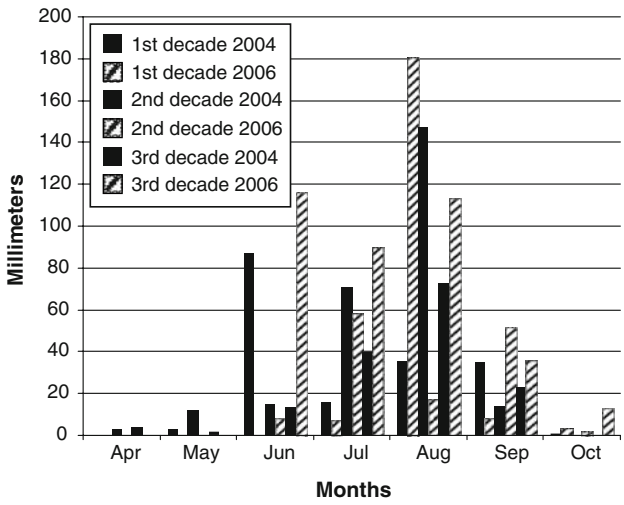

Fig. 1 Decadal rainfalls in Tougou during 2004 and 2006; source: 2iE institute (2007)

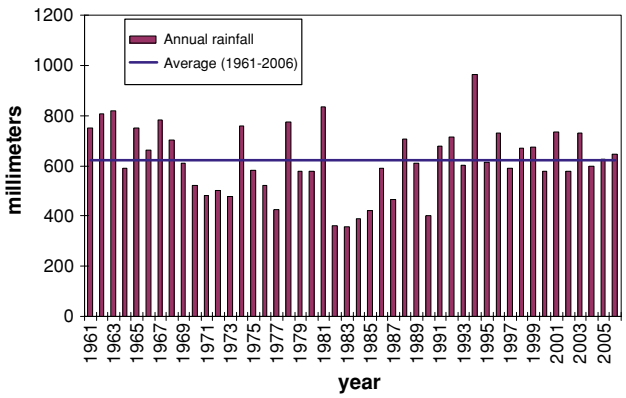

Fig. 2 Annual rainfalls in Ouahigouya from 1969 to 2006; source: Institut National de la Météorologie (2007)

Burkina Faso where land is still available and to Côte d'Ivoire where they mainly work in Cocoa plantations.

The community of Tougou consists of a typical ethnic mix of Fulanis and Mossis. Farming and non-farming activities (small trade, artecraft and gold mining) are typical to the region. The community has access to an irrigation scheme, which it shares with two other communities. Of the 8,228 Burkinabè communities, 1,254 have access to an irrigation scheme. However, the individual irrigation plots are so small that the impact of irrigation on vulnerability remains questionable.

The individuals interviewed were the heads of their respective extended families. An extended family is made up of several households, usually the father, his sons and their spouses. We use the term *farm* to refer to both extended and individual households. In rural Burkina Faso, the decision-maker regarding crop activities is usually the oldest man in the extended family. According to the survey, 86% of the so-called heads of the farms are the oldest males alive within the extended family. Many of the heads of farms interviewed asked their adult sons to respond to the questionnaire, suggesting that farming decisions were increasingly delegated to younger sons. Almost all heads of farms were illiterate (84%). Primary school enrollment is only 37%, but 80% percent of the farms send at least one child to school.

Because of permanent male out-migrations, the ratio of adult women to men was 1.5, favoring polygamy. Half of the extended families included at least one polygamous household. The majority of the farms had slightly fewer workers than non-workers, which is typical of farms with large numbers of children and migrants.

Results and Discussion

The results of the survey are organized around several topics. First, we discuss the results of the focus groups regarding farmers' perceptions of climate variability and its impact. Second, we expose the main characteristics of the farms. The next three sections detail major activities: land use, animal production, off-farm activities, and migrations. A separate section focuses on technological innovations. We then calculate and discuss the vulnerability index for two agricultural seasons. We finally analyze farmers' perceptions of various adaptation strategies and policy options.

Farmers' Perceptions of Climate Variability

Farmers' perceptions of climate variability were captured through focus groups. Most respondents experienced difficulties putting dates to past rainy seasons but could relate particular rainy seasons to some major political event or government. Most farmers hesitated to identify long-term rainfall trends, since farmers are mostly interested in particular characteristics of rainy seasons, not necessarily the total rainfalls. Farmers often described the current climate as drier than "before," but only older farmers could remember the more humid seasons of the 60s. Farmers did not speak easily of a recovery as scientists have described it and as one may to see in Fig. 2. Farmers were less interested in total rainfall than in distribution of the rainy season. When asked specifically about the increase of the rainfalls, farmers remained gloomy about the current state of the climate.

The importance of rainfall for crop and animal production was constantly stressed. Farmers' narratives concerning the impact of rainfall, heat and wind on crops were quite sophisticated. They could easily rank the impact of different aspects of rainy seasons (duration, regularity, intensity, and dry spells) on specific crop yields. The best yields came from long rainy seasons without dry spells during flowering time. The worst events of a rainy season are a dry spell when crops are fragile or a rainy season that stops too early before grains are mature. Even if they favored wet seasons, farmers mentioned that floods have a significant impact on crops planted in the lowlands. Also, excessive rainfall intensity can damage crops' growth during plant flowering.

Farmers had difficulties explaining their own adaptation strategies, because they consider that there is not much that can be done to mitigate risk. Adaptation strategies were considered a gamble with spiritual forces in which players should not display too much arrogance. When enumerators inquired about specific changes in farmers' practices in the past decades, farmers did not necessarily consider these changes as strategies designed to adapt to the climate. According to Tougou farmers, most changes were caused by land shortage and a decline in soil fertility, as if population growth was a more decisive factor than rainfall variability.

Land Use in Tougou

According to interviewed farmers, the arable land was completely cultivated. Farmers now cultivate the same fields quasi-permanently. Almost half of the farmers (47%) could no longer obtain new land in the community and no longer return cropped fields to fallow when fertility is exhausted. Three quarters of the farmers have already had to recuperate so-called exhausted fields. Farmers estimated that 60% of their fields were exhausted. Peanut, okra, and sesame are more suitable for such land, but these crops cover very small areas because of market constraints. In 1975, Marchal noted that 80% of the arable land of the

Yatenga province was cultivated and that 40% of the crops were planted on marginal land (Marchal 1977). Diello (2007), analyzing satellite images from the Nakanbè basin in which Tougou is located, shows that the cropped area increased quickly until 1992 but has been stagnating since. In Tougou, the cropped area was 10% smaller in 1992 than in 1973 because a large fraction of the marginal area in the south of the village territory was degraded by erosion. The cropped area stagnated between 1992 and 2002.

Average cropped area per farm is close to 5 ha during the rainy season (Table 1). As the average number of people per farm is 12, the area per person is close to 0.4 ha, which is the national norm (FAOSTAT 2004) and in line with other studies in the region (Matlon and Fafchamps 1988; Ouedraogo 2005). Two opposing factors are at play. One is mechanization with draft animal, which usually increases the cropped area per worker. The other is the expansion of crops onto more marginal land, which usually reduces the area per worker. Farmers in Tougou have been expanding plantations toward lowlands, where sorghum and sometimes maize are planted. Some lowlands have, using small dikes, planted rice. Farmers also plant more millet on marginal upland soils. Lowland and upland shallow soils require more labor than the common alfisols. The map drawn by Marchal shows in Tougou that the arable land covers around 1,500 ha, while an estimated 1,600 ha are currently cultivated.

To improve soil fertility, a majority of farmers use the *zaï* technique, which consists of hoeing small holes in the soil, into which farmers put small amounts of manure and plant sorghum and millet. This improves soil fertility and soil humidity. Half of the farmers also build stone bounds in their fields to capture runoff and reduce erosion. Most farmers now fertilize their soil with a small amount of organic matter, and some have started to apply inorganic fertilizers.

The dominant crops are millet and sorghum. Almost all farmers produce millet because of its resistance to drought and its tolerance of poor soil fertility. In 2004, because of the locust invasion and the drought, 30% of the farms reported no harvest at all, compared to 10% in 2006. In 2004, yields were low, close to 400 kilos per hectare. The same year, half of the farms had to buy millet; no millet was sold, and very little food aid was provided. In 2006, a wet rainy season, millet average yields increased to 600 kg.

Three quarters of the farms also produce sorghum. Those not producing sorghum have no access to lowlands, where sorghum grows best. During 2004, yields of sorghum were also very low, and sorghum's contribution to food intake was small (7%); no sorghum was sold, and a majority of farmers had to buy some. In 2006, a third of the farmers did not harvest any sorghum because most lowlands where sorghum was planted were flooded. Average yields were higher than in 2004 but still low. These values are in line with regional statistics and other studies (Ouedraogo 2005).

Surprisingly, the average areas of rice and maize are relatively large. Rice is mainly produced in the lowlands, and maize is produced mainly around the compounds, though some farmers have started to plant maize on the best land, where they were able to apply manure or contract herders to have their animals fertilize the fields. Maize yields were low in Tougou in both 2004 and 2006. The harvest starts early, improving farmers' food security. Beans are planted by almost all farmers within the millet and sorghum fields to take advantage of rainfall variability. Peanuts, fonio and sesame cover small areas.

Table 1 Farm production in Tougou

	Year	Millet	Sorghum	Maize	Rice	Bean
Involved farms (%)	2004	93%	71%	43%	22%	85%
	2006	93%	76%	41%	29%	82%
Area per farm (ha)	2004	2.53	1.50	0.42	0.14	Mixed
	2006	2.80	1.64	0.37	0.19	Mixed
Yield (kg ha^{-1})	2004	399	428	193	226	Mixed
	2006	609	482	257	376	Mixed

Animal Production

Animal production is almost as important as crop production in the Sahel. Most farms own some animals, which play a role in income generation and adaptation strategies. Cattle, donkeys, pigs, sheep, goats, and poultry provide complementary services to the farming system. In addition to meat and manure, cattle provide milk, oxen and donkeys provide draft animal, mammals provide leather, and poultry provide eggs. In Table 2, animal production strategies between 2004 and 2006 are compared.

Only a small fraction of the farmers own cattle, mainly Fulanis. The cattle population has recovered from the losses of the droughts of the 1970s and 1980s. Farmers consider herders richer than themselves today. In 2004, farmers and herders did not have to sell many cattle, and the mortality rate was low, though grass was scarce. Also, early rainfall triggered lung problems and locusts destroyed pastures, but the grass shortage was not as dramatic as in the 1980s.

The number of oxen used as draft animal among Tougou's farmers also increased from 2004 to 2006, but some had to sell more animals in 2004. The sale of oxen is not necessarily due to drought, as old oxen are often fattened and sold. Money from sales of oxen is usually not used directly to buy food. One fifth of the farmers fatten some bulls before selling them. There was slightly more fattening in 2006 than in 2004. Mortality was low in both years.

Table 2 Animal husbandry during dry and wet years in Tougou (% of farms involved)

	Years	Draft animal (%)	Fattened bull (%)	Sheep (%)	Goat (%)	Chicken (%)
Involved farms	2004	29	19	59	53	48
	2006	33	28	68	70	56
Sold	2004	18	13	47	42	36
	2006	11	8	24	18	25
Mortality	2004	5	4	28	25	44
	2006	5	4	15	12	16
Sold for food	2004	13	9	39	30	25

Half of the farms had to sell sheep and goats in 2004 to buy food. In 2006, the flocks had recovered and were already larger in size. One quarter of the farms reported sheep death during 2004, while losses were low in 2006. Half of the farms had no chickens at all, but one third had more than ten. In 2004, a third of the farmers sold some chickens, versus a quarter in 2006. Scores of chickens died during the drought. Surprisingly, in 2004, only one quarter of the sales of chickens were dedicated to buying food. Overall, farmers sell sheep, goats and chickens to cope with a failed rainy season, while cattle sales are part of a longer-term investment. According to our discussions, Fulani herders follow a typical accumulative strategy of small ruminants and cattle, while farmers are less interested in building large herds because of decreasing forage availability. Some farmers contract Fulanis to manage their cattle, but increasing distrust between the two communities is now hindering farmers' desire to accumulate cattle.

Off-Farm Activities and Migrations

According to our interviews, off-farm activities are pursued both to generate regular cash income and to reduce the risk of a failed rainy season. They include mainly small commercial activities, small scale gold mining, fishing in reservoirs and ponds, and the sale of wood and housing construction. One fifth of the heads of farms and one quarter of the dependant males had some kind of significant off-farm income. Women were said to engage more marginally in off-farm activities (16%).

A majority of farm heads has already worked in another country (60%), mainly Côte d'Ivoire. Most farms still have at least one relative who has permanently migrated out of the community (60%). Migration is a major adaptation strategy. After the drought of 2004, half the farms sent temporary migrants, versus only 13% in 2006. In 2004, 28% of the farms received remittances from migrants, versus 10% in 2006.

Perceptions of migration changed after the crisis in Côte d'Ivoire. A majority of farmers say that they prefer to invest in small-scale irrigation or gold mining rather than migrate. Other farmers told a more nuanced story. Many Burkinabè farmers have invested time and money in Côte d'Ivoire, notably in cocoa plantations. Even during the crisis, movement of migrants from Côte d'Ivoire was proportionally limited and temporary (Institut National de la Statistique et de la Démographie 2003). Regional policy is also heading toward greater integration and free mobility between countries. Ivoirians also need the Burkinabè migrants to provide necessary workers, especially for the cocoa plantations (Ruf 2006, 2007). Though farmers would prefer to work in their own communities, increasing land scarcity and lack of opportunities may continue to push a significant number of young farmers toward the south.

Technical Innovations in Crop Production

Farmers were asked their opinion regarding various new agricultural techniques. Did they adopt it? If no, do they plan to adopt it? (Table 3).

Irrigation of vegetables during the dry season was the most popular new activity in Tougou. A first modern scheme was built in the 1960s, 3 km from Tougou, but only a small number of farmers obtained plots of 0.25 ha. The beneficiaries have been producing two cycles of crops, rice and vegetables, for several decades. The system constructed then, with a canal distribution system, is still in use.

In 2005, because of the failed rainy season and the crisis in Côte d'Ivoire, farmers fenced around 10 ha of gardens upstream of the dam, around the artificial reservoir created by the dam. Farmers dug wells and temporary canals to irrigate onions and potatoes with gasoline-propelled pumps, with foot pumps or manually. Several groups of men and women were organized. Onions are by far the main production (60% of farms from Tougou are involved in onion production). Potatoes come in second and tomatoes, last. Most farmers in Tougou say they want to get more land around the lake, except Fulanis, who are more interested in cattle-rearing.

Supplemental irrigation during dry spells to secure the yields of rainfed crops such as sorghum was successfully tested in Tougou in 2003 (Fox and others 2005). Economic calculations showed that it was cost effective. However,

Table 3 Adoption of innovations in crop production (% of farms involved)

	Adopted (%)	Will adopt (%)	Will not adopt (%)
Stone bounds	60	18	22
Micro water harvesting (Zaï)	49	26	25
Water harvesting (half moon)	6	31	63
Soil restoration	49	16	35
Row planting	30	37	33
Improved seed	9	46	45
Plow	46	30	14
Draft animals	25	39	36
Weeder	10	37	53
Mineral fertilization of rainfed crops	21	8	71
Corralling (animal dung)	42	12	46
Manure	41	5	54
Compost (*Fosse fumière*)	56	31	13
More lowland production	51	14	35
Vegetable production	61	21	18
Fertilization of vegetables	59	11	30
Private insurance contract	0	59	41

the method was not adopted at all by farmers. Interviewed farmers do not consider that irrigating traditional crops during the rainy season makes sense. The area to irrigate is too large, and they believe that millet and sorghum will not benefit from irrigation. While farmers in Tougou do not irrigate maize during the rainy season, they do it during the dry season. Also, some farmers close to Tougou have started irrigating small areas of maize early at the beginning of the rainy season in order to harvest earlier and sell the production at a higher price.

Soil conservation practices have been widely adopted in Tougou in the past few decades. Half of the farmers have constructed stone bounds around some of their fields. A quarter of the non-adopters plan to construct some. Stone bounds are not required on flat land and can hinder mechanization. Half of the population already uses the *zaï* technique, and the non-adopters are divided equally between the willing and the reluctant. The "half moon" technique consists of digging large holes to capture runoff and planting sorghum in the holes. It has not been adopted yet because it is labor intensive, but a significant number of farmers said they are interested in applying this technique to the most degraded parts of their fields. Half of the farmers have had to recuperate degraded land, but few farmers plan to expand this practice. Most farmers do not plan to change land preparation before planting. Farmers plow with draft animals or plant directly in the field without plowing. Half of the farmers also expanded their fields toward the lowlands, mainly for sorghum, maize and rice production. The ones who did not have zero access to the lowlands or fear that floods will damage their crops.

Composting is now widespread in Tougou. Only a small fraction of farmers are still reluctant to produce it or do not have animals to get manure. A large number of farmers do some kind of corralling, meaning that they let their animals rest in their fields during the dry season. Some richer farmers contract herders to let cattle rest in their fields.

Adoption of improved seeds of rainfed crops was very low, but a large number of farmers express interest. Farmers do buy the expensive seeds of onions and potatoes. The use of fertilizers on rainfed crops is also low, and the vast majority considers it too expensive. Row planting (one of the central messages of the technical advisers) is not common, although many farmers show some interest. Row planting is linked to mechanized weeding with draft animals, bullocks, or donkeys (De Rouw 2004).

Half of the farmers own a plow, but only one quarter of the farms plow with animals, meaning that most plows are not used. This situation is common in the region, as many farmers obtained plows through generous programs, sometimes for free; but some beneficiaries were unable to obtain, train or feed the necessary animals. Weeders have not been widely adopted in Tougou, but a large group appears to be interested. Weeding time is a bottleneck of the cropping calendar.

Technical Innovations in Animal Production

Among the innovations adopted to improve animal production in Tougou, the most popular is the fattening of bulls and sheep (Table 4). Half of the farmers fatten sheep, and one third fatten bulls. Demand for mutton and beef has increased steadily over the last decade, especially among urban residents and also in Arab countries. Surprisingly, most interviewed farmers do not expect to expand animal production, referring to forage scarcity. This situation is an increasing issue in northern Burkina Faso, where the number of cattle is said to have diminished even when

Table 4 Adoption of innovations in animal productions (% of farms involved)

	Adopted (%)	Will adopt (%)	Will not adopt (%)
Bull fattening	47	19	34
More animals	13	32	55
Purchased feed	4	4	92
Hay	48	3	49
Sorghum stove	54	1	45
More milk production	4	10	86

rainfalls have improved. Many Fulani herders have moved to the southern half of the country, where population density is lower, pastures are still available and the *tse tse* fly is under control. Herders who remained in the region shortened their itineraries as reported in other Sahelian regions (Mc Carthy and Dutilly-Diané 2002).

Because of increasing grazing scarcity, crop residues are increasingly stored to feed livestock during the dry season. Half of the farmers in Tougou also harvest hay from natural grass. The non-adopters of these two techniques do not plan to expand this technique, as though it only concerns those who own animals. Purchased feed, such as cotton cake, is available in town but considered far too expensive by farmers in Tougou.

Very little milk is produced by the Fulanis' cattle in Tougou, even for those who own or manage significant herds. The vast majority of interviewed herders say that, because of lack of forage, they have no plans to significantly increase milk production. Hay and sorghum residues are not provided in a quantity that can increase milk production significantly.

The Vulnerability Index

The CILSS vulnerability index applied to our sample of farmers for a dry year (2004) and a wet year (2006) is presented in Table 5. In 2004, two thirds of the farms were unable to cover their grain needs. If the grain potentially bought by income generated by irrigated crops during the dry season is added, the number of vulnerable farms is reduced by 10%. Surprisingly, in 2006, a wet year, half of the farms were still vulnerable. When income from irrigation is included, the percentage of vulnerable farms is still 40%, and the percentage of very vulnerable farms is still 30%. These results suggest that Tougou is no longer self-sufficient, and farmers have to rely on non-farm incomes, remittances, and food aid to cover their basic food needs despite the development of small-scale irrigation.

Table 5 Preferred adaptation strategies in case of new droughts (% of farms)

Preferred adaptation strategies	% of farms
Animal sale	82
Less food	70
Less meals	56
Waiting for irrigation during the dry season	44
Diversification, improved seeds	32
Migrate to other regions	20
Change of grazing areas for cattle herds	15
Temporary migration	12
Other activities (gold mining, trade …)	10
More fertilization (organic matter, inorganic fertilizers)	06

Farmers confirmed this bleak situation; they consider their storage insufficient to cover their needs even after a wet year. In the past, they used to store grains for several years. The reasons for this decrease are both a smaller production per capita and a need for cash that does not permit the accumulation of significant grain reserves. Most farmers sell some grain at harvest time, store the rest, and buy food when the granary is empty. The low granary levels are probably an indicator of early sales due to an increased need for cash. Integration into the market probably means less self-sufficiency, but it remains to be seen if it means increased vulnerability. Farmers increasingly rely on off-farm jobs, remittances, animal sales and food aid. The traditional so-called "subsistence system" is being replaced by a semi-commercialized system (Ruthenberg 1980).

The food crisis of 2004/2005 in several Sahelian countries illustrates the new context. The crisis was one of buying power rather than of physical shortage (Cirad-Agrhymet 2005; République du Niger 2005). Farmers were unable to buy grain because the terms of trade were too unfavorable. While grain prices increased to unprecedented levels, most sources of farmers' incomes were depressed (animal prices, remittances from Côte d'Ivoire, remittances from the cotton area). According to our interviews, farmers reacted by intensifying vegetable production around the dams and by sending more young farmers into migration.

Preferred Adaptation Strategies

When asked about their adaptation to future droughts, few farmers consider migration (Table 6). Migration, permanent or temporary, is not popular because Côte d'Ivoire no longer welcomes migrants. Even short-term migration is considered a poor option. However, we interviewed only heads of farms, while the ones who migrate are usually younger dependents. One third of the adult males have already left the community in the past few decades.

Farmers insist upon their willingness to continue farming. There are too few job opportunities in the region, and illiteracy does not favor diversification toward off-farm activities.

The most common way of coping with new droughts is still to sell small animals. Farmers first sell chickens, goats and sheep. Only when the situation becomes critical do they sell cattle.

The second most practiced strategy is to reduce the number of meals per day and overall food intake. This situation was described extensively in 2005 by NGO reports. As most so-called "auto-insurances" failed, farmers had to reduce their food consumption.

Table 6 Vulnerability index after the 2004 and 2006 rainy seasons (% of farms)

	2004 ($N = 105$)		2006 ($N = 100$)	
	No irrigation	Irrigation	No irrigation	Irrigation
Very vulnerable (<90%)	60%	50%	41%	31%
Vulnerable (<90% and 110%)	9%	8%	8%	8%
Not vulnerable (>110%)	31%	42%	51%	61%

A more positive strategy proposed by farmers in Tougou would be to focus on irrigated vegetable production during the dry season. Income generated by this activity smooths food consumption because the sales occur until the end of the dry season when granaries are emptying.

In case of persistent drought, a third of the farmers will search for and use shorter cycle crop varieties. Others plan on having enough varieties with contrasting cycles. They do not necessarily need to look for new ones and might just need to reallocate the existing seeds between the different types of plots in case of a drier climate. Most farmers have never bought improved seeds from agricultural services. Some have gotten improved seeds for free through research programs.

In case of prolonged drought, most interviewed farmers would not try to improve soil fertility because they believe that improving soils makes sense when rainfalls are more regular. Also, if the climate gets drier, farmers will not be able to generate the income necessary to buy fertilizers or manure.

Most semi-nomadic herders say that they do not consider changing their traditional itinerary. Nomadism is inherently dependent on rainfall spatial distribution. However, some herders do not exclude moving south if a new series of droughts were to strike the area. Herders and farmers do not consider sales of cattle as a good risk-coping strategy, unlike the sale of small ruminants, which remains the usual way of dealing with the consequences of crop failure.

Policy Instruments Favoring Farmers' Adaptation to Droughts

Farmers were also asked to rank the best policy instruments to reduce poverty and vulnerability (Table 7). Agricultural credit was ranked first by a third of the interviewed farmers, and a fifth ranks it second. Before the early 90s, the government regularly provided credit for farm inputs and plows. International institutions asked for their cancellation under the structural adjustment programs (SAP) because most of these programs were unsustainable due to excessive default rates. Even during wet agricultural seasons it was difficult for subsistence farmers to generate the necessary cash to reimburse the debt. Credit was often reimbursed with remittances from migrants.

Table 7 Ranking of the best perceived policies by farmers (% of farms)

	1st	2nd	3rd
Credit	38	19	15
Irrigation	21	29	13
Food aid	14	7	10
Input price	8	33	17
Off-farm wage labor	8	7	6
Improved seeds	7	6	20
Insurance	1	4	11
Diversification	3	1	7
Migration	0	0	1

Some farmers get credit for input from the traders who buy their vegetables a few months later. These credits put farmers in a weaker position to discuss the prices at harvest time. Farmers do not regroup to get better bargaining power. In Tougou, an NGO has started to provide credit for vegetable production but formal credit is only provided to the rare well-organized cooperatives.

The so called microcredit programs proposed by NGOs are usually not tailored to assist agricultural production. They are more short-term, often aimed at women engaged in small commercial activities (Nguyen and others 2002). There is no "credit for storage" program in Tougou, and farmers did not consider this scheme useful because a project recently mismanaged such a scheme in the community.

The second most popular policy is providing irrigation. Irrigation in Burkina Faso is central to the government's fight against poverty (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques du Burkina Faso 2003). More than 1,400 small dams have been built after the droughts of the 1970s. The government and some NGOs also invested in sophisticated canal irrigation schemes. Around 10,000 ha of small-, medium-, and large-scale irrigated schemes (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques 2003) produce rice during the wet season, with the remaining water devoted to producing rice or vegetables during the dry season. Modern schemes concern only a small fraction of national vegetable production.

The last decade has seen the fast development of informal gardens around reservoirs and in some lowlands where small farmers produce vegetables during the dry season. Three quarters of the farmers involved in vegetable production lift water from wells by hand, 17% use gasoline propelled pumps and only 4% benefit from modern gravity systems (DGPSA 2004). At first, informal irrigation was marginal because gardening around the artificial lakes was mostly prohibited for fear of sedimentation, and access to the market for non-traditional crops such as fruits or vegetables was poor. The political crisis in Côte d'Ivoire has favored the push of young Burkinabè farmers toward the land around the dams. Statistical services estimate that 8,800 ha of vegetables are now cultivated by an estimated 200,000 farmers, one third of them women (Ministère de l'environnement et de l'eau du Burkina Faso 2001; Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques 2003; Sanfo and others 2008; Traoré 2007).

Fixed costs of these informal gardens are much lower than for modern schemes with cemented canals, drainage systems and protection against floods. Informal irrigation requires intensive effort by hand or by small, gasoline-propelled machines but wastes less water than irrigated schemes, where the water distribution system put it in place by the technicians is usually not well respected (Kinane 2008). Informal irrigation is probably less vulnerable to climate conditions. If the reservoir does not fill up during a drought, farmers still can adapt the location of their field by moving closer to the artificial lake or by digging deeper wells. However, one should not overestimate the impact of a very dry rainy season on overall water availability.

One increasing problem is that the development of the informal gardens is leading to the overexploitation of the water potential of the existing reservoirs. In many places, as in Tougou, farmers have to plant vegetables much earlier to be sure to harvest before the reservoir dries up.

The third most popular policy is food aid. Food aid systems have been reorganized in the Sahel, since the government and NGOs have progressively put in place a common strategy based on direct aid to the most vulnerable, subsidized sales of grain in local markets and "food for work" programs. During the food crisis of 2004/2005, farmers in Tougou received some support but have been complaining about the poor impact of the new system. Some complained that the criteria for targeting the most vulnerable communities are not disclosed, creating frustration toward the system.

The fourth most demanded policy is subsidizing of fertilizer prices. The disappearance of fallows requires the use of inorganic fertilizers because the existing techniques to maintain or restore soil fertility are insufficient (Pieri 1992). Also, fertilizers are required for vegetable production. Fertilizer prices have increased with the price of fuel, since nitrogen production is energy intensive and fertilizer costs are related to transport from the coast. Fertilizers were subsidized in the past but were mostly cancelled in the early 1990s under the SAP.

The fifth most popular policy is providing jobs, such as the food for work programs developed in the Sahel after the droughts of the 1970s. Improving farmers' buying power is considered one of the best policies for reducing poverty and vulnerability. Burkina Faso cannot provide many jobs in the industrial sector because the cost of energy, the highest in the world, hinders industrial development; but jobs can be created in building infrastructure such as roads and small dams.

No farmers thought that facilitating migrations was a good policy, though this might have been the best policy for alleviating poverty in the Sahel after the droughts of the 1970s, when hundreds of thousands of Sahelian farmers migrated to Côte d'Ivoire to participate in the cocoa boom. Around two million Burkinabè still live there, sending remittances to their families back home. According to interviews, the recent crisis in Côte d'Ivoire has probably increased Sahelian farmers' vulnerability, and the Burkinabè government is participating in the resolution of the conflict.

Providing improved seed for rainfed crops is rarely mentioned as a useful policy. Farmers do not expect to buy improved seeds for rainfed crops. Seeds for vegetable production, however, are in demand, and farmers demand credit with a reasonable credit rate.

Individual insurance is not considered a sound policy because farmers have no experience in such schemes. When a scheme based on rainfall levels measured with local rain gauges was explained, half the farmers displayed distrust, while the other half said they would enroll. Tougou's farmers note that drought is not the only source of income variability. In 2004 crops were destroyed by locusts, not by droughts, and in 2006 and 2007 a significant area was destroyed by floods.

Farmers do not consider seasonal forecasts a serious instrument for reducing risk. None had heard of the seasonal forecast provided by CILSS before the beginning of the rainy season. First, farmers express disbelief toward the validity of such predictions. Second, they feel constrained by lack of capital for adapting their system to the predictions. Only a few mentioned how they would allocate their crops differently between lowland and upland fields. In case of a wetter season that could flood the lowland, they would plant more into upland and try to plant more maize around their compounds. In case of a predicted drought, they would plant more rice, sorghum or maize in the lowland. Such theoretical strategies have been explained in previous studies (Ingram and others 2002).

Conclusion

The first conclusion is that the population of Tougou is still chronically vulnerable. According to the vulnerability index, two thirds of the farms were very vulnerable in 2004, when locusts destroyed the crops, and 40% were still vulnerable in 2006 when the season was wet and locusts gone. The reason is that yields remain low even when it rains because traditional varieties and seeds, and probably soil fertility, constrain crop development. Farmers explain that on most of the land, soil fertility is too low to adopt more productive crops such as sorghum or maize. According to the interviews, incomes increasingly come from off-farm activities, remittances, dry season vegetable production and animal fattening, which are less directly related to the quality of the rainy season.

The second conclusion of this study is that farmers from Tougou have adopted a large array of new techniques such as small-scale irrigation, soil and water conservation techniques, water harvesting, forage conservation, animal fattening, and mechanization with draft animals. The level of adoption observed in Tougou is similar to that observed in the region by other studies. Most techniques aim at increasing production in average years but can also reduce production variation during droughts.

The third conclusion is that farmers consider land scarcity to be the major driver of adaptations. During the focus group discussions, farmers pinpointed land scarcity as a major limiting factor of crop production increase. It was easier to increase production when land was available than to increase yields. Most new techniques were adopted because the fallow system had to be replaced by a more permanent agriculture. However, most of the farmers' adopted techniques also reduce their crop and livestock vulnerability to climate variability.

The fourth conclusion is that small scale irrigation during the dry season has become a popular alternative to migration, as it reduces farmers' vulnerability even on very small plots. After the 2004/2005 food crisis, young farmers and women regrouped to start cultivating onions near the dam. Small-scale irrigation is becoming significant in Burkina Faso around the 1,400 dams. The development of vegetable production in the Sahel is sustained by a growing demand from cities and coastal countries. Vegetable prices are very variable but are less related to climate than rainfed crops and can serve as a significant risk-coping strategy.

A fifth conclusion is that the future of rainfed farming remains challenging. Farmers adopted several soil conservation practices, such as stone bounds, *zai*, composting and manuring. However, even when it rains, yields remain low. The challenge of replacing the fallow system with permanent cropping in the highly populated Sahelian regions is significant. Inorganic fertilization is considered too expensive, and input credit is not available. Also, organic fertilization requires much more biomass and manure than is currently available. Supplemental irrigation of rainfed crops is not popular. Increasing yields is technically possible, but according to farmers, the major limiting factor is access to capital.

The final conclusion is that the two most popular policy instruments among farmers from Tougou are credit programs and irrigation. While the prospect for credit schemes for rainfed production remains bleak, formal and informal credit is developing for vegetable production because it generates more cash in a shorter time. A well-functioning vegetable sector could boost the other sectors, such as rainfed crops, livestock production, and off-farm activities. Since vegetable production is less dependent upon the climate, it is possible that the impact of vegetable production, even if it is on a small scale, could have a significant risk-reducing impact and could progressively improve farmers' capacity to invest in other sectors.

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