Climate Change and Variability in the Sahel Region:
Impacts and Adaptation Strategies in the Agricultural Sector

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Climate Change and Variability in the Sahel Region:
Impacts and Adaptation Strategies in the Agricultural Sector

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Abstract

The Sahel is highly vulnerable to climate change due its geographic location at the southern edge of the Sahara desert and the strong dependence of its population on rainfed agriculture and livestock. The primary sector employs more than 60 percent of the active population and contributes 40 percent of the Gross Domestic Product (GDP) of the region. Rainfall variability, land degradation and desertification are some of the factors that combine to make life extremely difficult in this part of the world. The recurrent droughts of the 1970's and 1980's (the Sahel desiccation) represented a particularly trying episode for the Sahelian countries, with massive losses of agricultural production and livestock; loss of human lives to hunger, malnutrition and diseases; massive displacements of people and shattered economies. Yet, most climate models predict that the Sahel region will be drier in the 21st century. Even slight increases in rainfall are unlikely to reverse the situation since a hotter climate means that evapotranspiration will be more intense, exacerbating the already arid conditions. Thus, climate change may become the greatest obstacle to the achievement of the Millennium Development Goals (MDGs) to which the Sahelian countries have subscribed.

The objective of this paper was to document some of the mechanisms the Sahelian communities have used to cope with current climate variability, and the contribution of scientific research and technological innovations in addressing the major constraints of drought, land degradation and desertification. The assumption is that if these indigenous resources and technological innovations are effective to cope with current climate variability and other constraints, they will probably be useful to deal with future climate change. The review showed that local people have developed and used a rich repertoire of strategies, ranging from diversifying crop production and harvesting wild fruits and other tree products; to raising cattle and doing business and other paid jobs; to migration to cities and other countries to earn a living. Indeed, these strategies have helped the rural people absorb some of the pressure posed by climate variability and other sources of stress. However, the severity of the 1970's and 1980's droughts stretched these indigenous coping methods to their limit. Rainfall has become less reliable and growing seasons shorter in many areas, which inevitably required a radical shift in farming practices.

A wide range of innovations have been developed through strategic research partnerships, and these have had a great potential in bringing solutions to problems such as drought and low soil fertility that impede agricultural production in the Sahel. These include: (1) the development and release of crop varieties that tolerate mid-season drought or mature early enough to avoid terminal droughts, which have become more frequent in recent years; (2) soil and water conservation techniques that restore degraded lands and store water in the soil; and (3) agroforestry technologies that restore soil fertility, control soil erosion and desertification, improve microclimate and provide fruits, fodder, wood and other useful products. Whereas these technologies have shown great potential in stabilising agricultural production, improving food security and reducing poverty in the short-term, they are also likely to make agriculture more resilient in the face of future climate change. However, reaching the millions of climatically vulnerable farmers in the region for a wider aggregate impact is the biggest challenge. Doing so will require that a number of technical, socio-economic and institutional obstacles be identified and dealt with through adequate policies. Some of these obstacles and knowledge gaps are discussed in the paper.

1. Introduction

Efforts to address climate change have so far focused on two response strategies: mitigation and adaptation. This has been strongly stated in the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Mitigation seeks to reduce greenhouse gas (GHG) emissions to avoid further warming of the globe. Adaptation, on the other hand, aims to cope with the problem of climate impacts when they materialise (IPPC, 2001; Huq and Reid, 2004). However, climate discussions in the early years of the Convention were overwhelmingly dominated by mitigation while little consideration was given to adaptation. This was, to a great extent, due to the early perception of climate change as something that was going to occur in a gradual fashion in the medium- to long-term (i.e. in the next 50 to 100 years).

Now our understanding of climate change has considerably improved. Several sources including the assessment reports produced by the Intergovernmental Panel on Climate Change (IPCC), the National Communications (NCs) of the parties to the Convention and direct observations on the ground are increasingly providing evidence that climate change is actually happening much faster than initially assessed and that the consequences are already visible in many areas of the world. This, without any doubt, has triggered a renewal of interest in adaptation. But another decisive factor that has contributed to bringing the adaptation debate back to the negotiation table is the resolve of the developing countries, which are now voicing their concerns more vigorously and asking for immediate actions. Most of these countries, which include the Least Developed Countries (LDCs) and the Small Island Developing States (SIDS), have an insignificant share of the global Greenhouse gas (GHG) emissions, but will suffer more severely from the negative impacts of climate change due to their low adaptive capacity (Pachauri, 2004). The Sahelian countries are particularly vulnerable because not only do they almost all belong to the LDC group (Cape Verde has graduated from the LDCs but is a SIDS nonetheless) but also their geographic location just at the southern age of the Sahara desert exposes them to particularly harsh climatic conditions.

Like in most of Africa, agriculture is an important sector in the Sahelian countries given its multiple roles in food security, employment and contribution to national Gross Domestic Products (GDPs). The paradox, however, is that agriculture in these countries remains a highly under-developed sector, characterised by (1) an almost total dependency on rainfall; (2) low use of external inputs such as improved seeds and fertilisers; (3) absence of mechanisation; and (4) poor linkage to markets. This makes agriculture highly vulnerable to climate change. Yet, people who depend on this activity for their livelihoods have faced a large variety of shocks (including climate variability and extremes) to which they have responded, based on traditional knowledge or by devising innovative measures when faced with new sets of constraints. Also, research over the last few decades has devoted a lot of efforts on the development of useful technologies in response to the various constraints and stresses facing agriculture in the Sahel region.

The objective of this paper is three-fold:

1. to document the changes that have occurred to the Sahelian climate over the last few decades and the consequences these changes have had on the populations and economies;
2. to analyse the prospects of future climate change in the Sahel, its implications on the agricultural sector and the various strategies that are being put in place by the various countries;
3. to draw the attention of adaptation experts and policy makers on the possible role of agricultural research in adaptation to climate change in the Sahel region.

2. Particularity of the Sahel

2.1. Brief presentation

The Sahel represents the southern edge of the Sahara desert, extending at least 4,500 km from Cape Verde through Senegal, Mauritania, Mali, Burkina Faso, Niger, and Chad, and is limited to the south by the less arid Sudano-Sahelian belt. It is a transitional zone between the arid Sahara and the tropical green forest that borders the maritime coast. The vegetation cover of the Sahel is composed of bushes, grasses and stunted trees that increase in density as one moves southward (CILSS, 2004). It is however difficult to give precise latitudinal limits to the Sahel since these are subject to fluctuations, depending on rainfall patterns.

Today, more than a mere eco-climatic zone, the term 'Sahel' also refers to a geopolitical entity. In 1973, nine west-African countries (Figure 1) formed the Permanent Interstates Committee for Drought Control in the Sahel (CILSS). The CILSS ensemble covers approximately 5.7 million km2 and is home to about 58 million people (Table 1). These countries not only share similar climatic conditions (the Sahelian climate), but their inhabitants have a lot in common in terms of cultures and livelihood systems. These livelihood strategies include agriculture, livestock herding, fishing, short and long-distance trading, and a variety of urban occupations. Dryland crops such as millet, sorghum and cowpea constitute the staple foods of the populations while groundnut and cotton are the major cash crops. Farming in this region is almost entirely reliant on three to four months of summer rainfall, except along the banks of the major rivers, lakes, and other seasonal water courses, where some irrigation activities are undertaken. Livestock herding is a very important aspect of life and constitutes the major source of income in some areas.

Table 1. Member countries of the Permanent Interstates Committee for Drought Control in the Sahel (CILSS, 2004).

Country	Area (km2)	Population (Million)	Per capita GNP (US$)	HDI
Burkina Faso	274,000	12.3	240	0.320 (159e)
Cape Verde	4,030	0.43	1207	0.708 (91e)
Chad	1,284,000	8.7	210	0.359 (155e)
Gambia	11,295	1.4	498	0.398 (149e)
Guinea Bissau	36,125	1.3	160	0.339 (156e)
Mali	1,240,190	11	240	0.378 (153e)
Mauritania	1,025,520	2.7	390	0.437 (139e)
Niger	1,267,000	10.4	190	0.274 (161e)
Senegal	196,722	9.7	500	0.423 (145e)
CILSS	5, 664, 007	57. 93		

Figure 1. Geographic location of the CILSS member countries within Africa

2.2. Why is the Sahel so vulnerable?

2.2.1. The climate

The Sahel is characterised by strong climatic variations and an irregular rainfall that ranges between 200 mm and 600 mm with coefficients of variation ranging from 15 to 30 percent (Fox and Rockström, 2003; CILSS, 2004). Agriculture is predominantly rainfed and depends on 3 to 4 months of summer rainfall. The succession of dry years and wet years is a typical feature of the Sahelian climate (Figure 2). In fact, extreme years are so frequent that some analysts argue whether the notion of 'normal rainfall' is relevant in the context of the Sahel (Hulme, 2001). Thus, the natural and societal systems in this part of the world owe their existence to their capacity to adapt to this fluctuating rainfall supply (Raynaut, 2001; Mortimore and Adams, 2001). Droughts with varying degrees of severity occur in two out of every five years, making harvests of the major food and cash crops highly uncertain (Hengsdijk and van Keulen, 2002). Climate variability therefore poses one of the biggest obstacles to the achievement of food security and poverty reduction in the region.

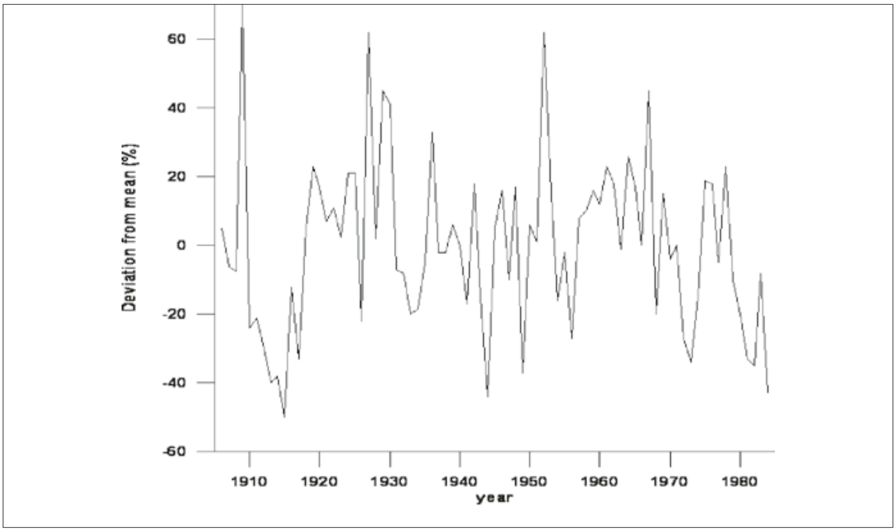

Figure 2. Percentage deviation of annual rainfall at Niamey, Niger

In the 20th century, the Sahel region experienced three major drought periods including 1910–1916, 1941–1945 and the long period of sustained declining rainfall (the 'desiccation') that spanned the 1970s and most of the 1980s and continued with some interruptions into the 1990s (Batterbury, 2001; Hall et al., 2003). The desiccation was a dramatic episode for the young Sahelian nations. The annual rainfall values of 1983 and 1984 were among the lowest ever recorded in the history of the Sahel, but severe droughts also occurred in 1972, 1973 and 1977 (see Hulme, 2001). In 1984, drought severely affected all countries from Mauritania to Ethiopia, including several bordering countries on the southern edge of the Sahel. In contrast, the1973 drought was more localised and affected mostly Mali, Niger and Chad.

2.2.2. Soil resources and land management

Soils in the Sahel are inherently fragile, low in carbon and poor in plants nutrients (Manlay et al., 2002 a; b; Gandah et al., 2003). Therefore, when these soils are poorly managed (as is often the case), the outcome in terms of human welfare and environmental sustainability can be dramatic. Maintaining soil fertility, whether through organic or inorganic sources, is the key to sustainable agriculture. In the Sahel, the use of fertilisers is very limited (Table 2) and there are many reasons for that. First, millet and sorghum, the major cereal crops in the region, are considered low value, i.e., the little income these hard grains are able to generate does not make investing in fertilisers an attractive enterprise. Second, the local varieties have low yield potential and therefore are not effective in using fertilisers. Third, the risks of crop failure are high due to the frequency of droughts and other yield-reducing factors such as pests, diseases and weeds. Fourth, poor road infrastructures and access to markets in rural areas make both physical and economic access to fertilisers a major problem to many small holder farmers.

Table 2. Nitrogenous fertiliser consumption (tonnes) in 4 Sahelian countries between 1972 and 2002. Source FAOSTAT

	1972	1982	1992	2002
Burkina Faso	584	3310	9306	926
Mali	3104	5559	10700	14000
Niger	212	1344	900	3360
Senegal	5176	3400	9000	21382
Sahel average	2269	3403	7476	9917
African average	23519	41186	45262	56110
World average	254536	399821	438436	489863

The increase in aggregate food production (per capita food production has been declining due to rapid population growth), which has been observed in the Sahel and many other parts of sub-Saharan Africa since the early 1980s, has primarily been driven by the continued expansion of the cultivated areas (Figure 3). In the same time, yields of the major cereal crops have been stagnating, with the exception of maize, which has followed a relatively steady progression since the mid-1970s (Figure 4). Still, maize yields are very low compared to the potential of the varieties used. The consequence of such an 'expansion only' strategy of food production is the mining of nutrients and the deterioration of the land resources especially when marginal lands are brought under crop production. In many areas, the disappearance of fallows and the shrinking of pastures have led to overgrazing, which has equally devastating consequences on land resources.

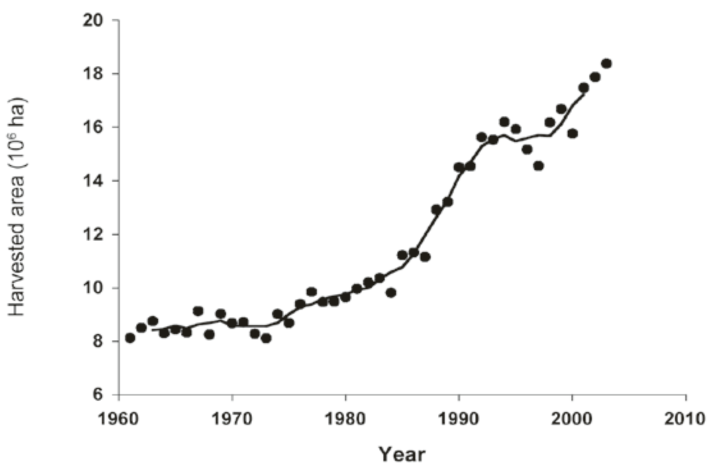

Figure 3. Total area harvested to cereals in the Sahel since 1961 (data from FAOSTAT)

Whereas the soils in vast areas of the Sahel are inherently fragile and prone to degradation, the nature of the precipitation does not make the situation any better. With the torrential summer rains, water absorption by the soil is very difficult, especially if the latter is bare. The composition of many soils in the Sahel (high levels of sand and silt, and low levels of clay) makes them highly prone to crusting when 'battered' by the heavy raindrops, especially during the first storms (Fox and Rockström, 2003). As a result, water runoff rates of 40 percent of total annual rainfall are common in these landscapes. Along these water losses, erosion is an important mechanism of degradation with annual soil losses of up to 100 tonnes per hectare per year. In some areas and because of the absence of trees, wind erosion can induce an additional annual soil loss of more than 150 tonnes per hectare (Pasternak et al., 2005). The loss of the topsoil (which contains most of the plant nutrients) through water and wind erosion is a major setback to agricultural sustainability and food security in the Sahel. If this is true (there is a strong debate on the relationship between soil loss and crop yield, see Warren et al., 2001), then unfortunately, the Sahel is almost inevitably heading towards an environmental disaster, for the simple reason that investment in erosion control ranks very low on the farmers' hierarchy of priorities.

Arguably, the most sensible and economical way of controlling erosion in the Sahel would be to leave the vegetation cover on the soil surface and clear the fields only after the end of the first storms, which bring along the strong winds and the heavy downpours. However, doing so in an environment where the growing season is already too short and the sequence of rainy events so random may be suicidal, for missing those initial rains can be tantamount to missing the season altogether. Farmers are cognizant of some of the short-term effects of soil erosion such as sand blasts or the unearthing/burial of seedlings, but they view them as occasional and minor occurrences as compared to other problems such as drought or pests, for example. Experience tells them that clearing and seeding before, or exactly at, the onset of the first rains to catch maximum water is a much more rewarding strategy. This imperative largely overrides concerns over soil erosion issues (Warren, 2002). Thus, beyond a highly capricious climate, it is the survival strategy of farmers – of which 'negotiating the rain' (Mortimore and Adams, 2001) is a major component – which is the very cause of soil erosion in the Sahel. So unless radical changes happen, soil erosion is going to be even more problematic in the near future given the continued expansion of cropping lands due to population growth.

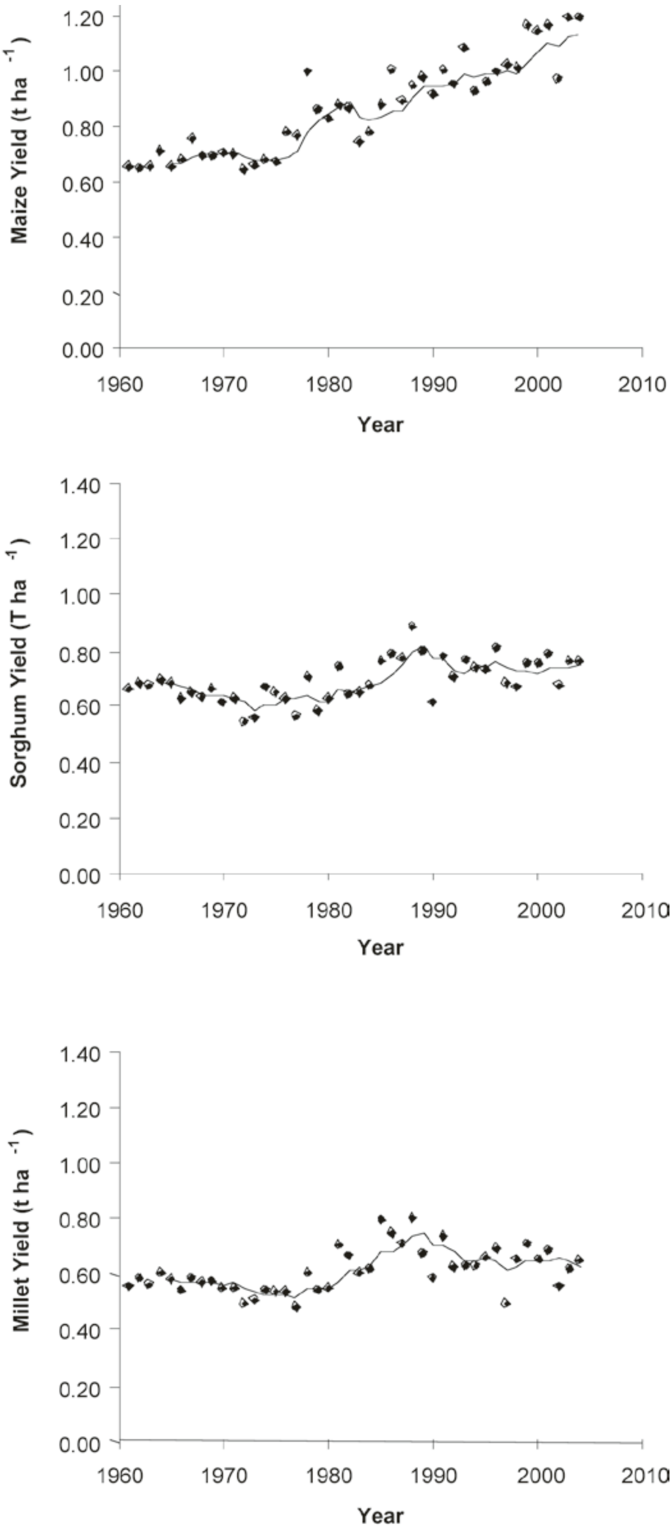

Figure 4. Averaged maize, sorghum and millet yield for the nine CILSS member countries since 1961 (data from FAOSTAT)

2.3. Conclusion

Rainfall variability is a major driver of vulnerability in the Sahel. However, blaming the 'environmental crisis' on low and irregular annual rainfall alone would amount to a sheer oversimplification and misunderstanding of the Sahelian dynamics. Climate is nothing but one element in a complex combination of processes that has made agriculture and livestock farming highly unproductive. Over the last half century, the combined effects of population growth, land degradation (deforestation, continuous cropping and overgrazing), reduced and erratic rainfall, lack of coherent environmental policies and misplaced development priorities, have contributed to transform a large proportion of the Sahel into barren land, resulting in the deterioration of the soil and water resources. The intertwined processes of land degradation and desertification, which have prevailed in the Sahel over the last few decades, are nothing more than the embodiment of a degenerative process that started several decades back. The drought years of the 1970s, 1980s and 1990s were not necessarily the cause, but certainly the culmination, of this environmental crisis. Even if rainfall has come back to near-normal and food security improved in recent years, the Sahel remains an environmentally sensitive region and climate change is likely to exacerbate the vulnerability of its ecological and socio-economic systems.

3. Is the climate changing in the Sahel?

3.1. Climatic trends in the 20th century

There is now scientific consensus that the global climate is changing. Global mean temperature increased by 0.6 degree C in the last century, with the hottest years ever in record occurring after 1990. This warming of the world climate has been linked to a higher concentration of greenhouse gases (GHGs) in the atmosphere, the consequences of which can be manifested in the higher frequency of extremes such as floods, droughts and cyclones. The Sahel region has had its fair share of changes. While rainfall variability is a major characteristic of the Sahelian climate, the second half of the 20th century has witnessed a dramatic reduction in mean annual rainfall throughout the region (Diop, 1996; Le Barbé and Lebel, 1997; Hulme, 2001; Camberlin and Diop, 2003; Giannini et al., 2003; Dai et al., 2004) as illustrated by Figure 5. According to the IPCC, a rainfall decrease of 29–49 percent has been observed in the 1968–1997 period compared to the 1931–1960 baseline period within the Sahel region (IPCC, 2001).

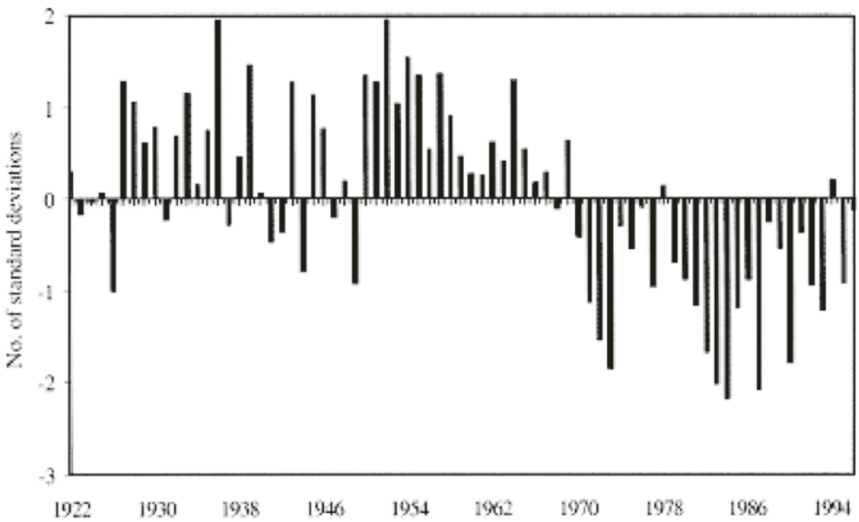

Figure 5. Rainfall in the Sahel between 1922 and 1996 (Ahmed et al., 2000)

It is however worth noting that although the entire Sahel region was affected by the drying, the way this was manifested varied from one area to another. A recent study conducted in Senegal showed a significant trend towards earlier cessation dates of the summer rains over the 43 year period between 1950 and 1992, with an abrupt shift occurring around 1970 (Camberlin and Diop, 2003). Average cessation date shifted from 9th October in the 1950–1969 period to 25th September in the 1970–1992 period. A small trend towards delayed onset has also been observed in recent years resulting in shorter growing seasons. Similar studies conducted in Northern Benin (Houndenou and Hernandez, 1998) and in Cape Verde (see Cape Verde initial NC) also showed a decreasing trend in the duration of the wet season. In Mali, however, Traore et al. (2000) found a relative stability of the onset and cessation dates in the periods 1959–1978 and 1979–1998 despite much lower rainfall in the latter period. A detailed re-analysis of rainfall data over the last few decades in Niger led to a similar conclusion since the decrease in mean annual rainfall since 1970 was attributable to 30 percent less rains in the period of maximum rain, but not to a reduction in the length of the growing season (Le Barbé and Lebel, 1997).

This downward trend of annual rainfall over the Sahel ended in 1988, which marked the reappearance of 'normal' rainfall years. Whether the run of good and average rainfall years recorded since the late 1980s announces the end of the Sahelian drying is difficult to tell. Another question that remains unanswered is whether the drying was a manifestation of long-term climate change or just a protracted cycle similar to periods of extreme El Niño and La Niña events that caused major famines in China, India, Ethiopia and Brazil towards the end of the nineteenth century (Devereux and Edwards, 2004). Whatever the case, one thing has remained (and will remain) unchanged: rainfall fluctuation will continue to plague the Sahelians. Enhancing the capacity of the Sahelian nations and the populations to anticipate and cope with those variations will be the only way out of the environmental 'crisis' in which the Sahel has been trapped for so long. This is all the more necessary that climate change is likely to increase the frequency of extremes such as droughts and floods in the region.

3.2. Future changes

While much is known about the climatic past and present of the Sahel, predicting what its future climate will be appears to be a more complicated task. In the third assessment report (TAR) of the IPCC, general circulation model (GCM) simulations suggest a future warming of 0.2°C per decade (low warming scenario) to more than 0.5 °C per decade (high warming scenario) across the African region, with warming expected to be greatest in the interior of the Sahel and in central southern Africa (Carter et al., 2000; Hulme et al., 2001). Rainfall increases may also be expected in the Sahel, but only with the most rapid global change scenario. Hulme et al. (2001) tested the extent of inter-model differences in relation to future rainfall changes over three regions in Africa and predicted wetting in east Africa and drying in southeast Africa. However, none of the models showed a clear outcome for the Sahel region. There remains, therefore, many uncertainties vis-à-vis the future climate of the Sahel.

The initial NCs give a more detailed account of climate change scenarios and their implications in relation to the most vulnerable systems and sectors such as agriculture (see sub-section 5.2)

4. Implication of climate variability/change for the Sahel

4.1. The socio-economic impacts of the drying

The downward trend of rainfall during the 1960–1970 decade affected the whole African continent but the people who were worst hit, were those who lived in low rainfall areas. The prolonged drought that afflicted the Sahel region from the late 1960s through to the 1980s, and the tragic consequences it had on its people and economies, was a wake up call to the international community (Batterbury, 2001; Mortimore and Adams, 2001; Raynaut, 2001; Batterbury, 2004). The rural communities, who depended on farming and herding, were badly affected with an estimated 100,000 drought-related deaths. The drought also triggered an unprecedented tide of mass migration from North to South (within countries), from rural areas to nearby cities, and from landlocked to neighbouring coastal states and other continents.

The desiccation has had far reaching consequences on the Sahelian countries, which are home to some of the poorest in the world (Table 1) and whose economies are heavily based on agriculture and livestock. This sector employs more than half of the active population and contributes to about 40 percent of the GDP (CILSS, 2004). The prolonged droughts further stretched the meagre resources of these countries, with devastating consequences such as hunger and malnutrition, deterioration of soil and water resources, desertification and widespread misery. Many people migrated in search of relief. Squatter settlements and urban overcrowding increased, accompanied by rising unemployment. Additional burdens were placed on limited social services, and political instability intensified in many countries.

Chad, the largest country in the Sahel region, epitomises the tragedy of the 1970s. It is estimated that more than 900,000 people were severely affected by the drought, although the actual number of starvation victims and displaced people is unknown (DMC, 1995). The important shortfall in crop production and massive death of livestock had overwhelming economic implications. In 1973, the gross domestic product (GDP) of Chad had a negative growth of 9 percent. The loss in real economic growth was a devastating setback for the country since per capita gross national product (GNP) dropped to US$ 120 by 1975, ranking Chad as one of the lowest income countries in the world (DMC, 1995). The 1984 drought had similar impacts on Mali and Niger, who saw their GDP fall by 9 and 18 percent respectively in the aftermath of the drought (World Conference on Disaster Reduction, 1994).

4.2. Climate change and food security

Although there is no general consensus on the direction changes in precipitations will take in the future, climate change may have negative consequences on agricultural production and food security in the Sahel region. Arid conditions are likely to be exacerbated even in places where an increase in precipitation is predicted because of a higher evapotranspiration regime due to higher temperatures. Extremes in the form of droughts and floods will be more frequent, putting an additional pressure on already stressed systems. While global food supplies may not be affected by future shifts in climate due to gains in arable land from boreal and temperate areas, many projections show Africa losing a significant part of its arable land and the Sahel will be among the worst affected regions. A climate sensitivity analysis of agriculture concluded that three African countries will virtually lose their entire rain-fed agriculture by 2100 (Mendelsohn et al., 2000) and two of them are Sahelian countries: Chad and Niger. A recent simulation exercise in Mali (assuming a temperature rise of between 1 and 2.75 degree C and no adaptation measures applied) suggests that, by the year 2030, reduced precipitation will induce a decline in cereal harvest of 15–19 percent causing a doubling of food prices. The combined effects of lower production on farming household and higher prices on the consumer's access to food raises the risk of hunger from its present baseline of 34 percent to 64–70 percent of the Malian population by 2030 (Butt et al., 2003).

4.3. Climate change and the Millennium Development Goals (MDGs)

The millennium summit was held in New York in 2000 to examine the steps required to achieve a rapid path to sustainable development in the world. Eight goals were proposed to serve as barometers for monitoring progress towards achieving sustainable development with 1990 as baseline year and 2015 as target year (UNDP, 2003):

Goal 1: eradicate extreme poverty and hunger
Goal 2: achieve universal primary education
Goal 3: promote gender equality and empower women
Goal 4: reduce child mortality
Goal 5: improve maternal health
Goal 6: combat HIV/AIDS, malaria and other diseases
Goal 7: ensure environmental sustainability
Goal 8: develop a global partnership for development

The Sahelian nations, like other developing countries, subscribed to these goals and pledged to take the necessary measures to meet them. However, the analysis of the latest country MDG reports indicates that only few of these countries are making enough progress to meet some goals and none will meet all of them if the current trends are maintained. Halving poverty by 2015 is undoubtedly one the most daunting challenges. Although some countries have enjoyed regular economic growth since the devaluation of the CFA Franc (the regional currency for French west and central Africa) in 1994, the benefits of this growth have not trickled down to the most vulnerable segments of the society. A structural analysis of poverty shows that the Gini Coefficient (a measure of inequality) has followed its upward trend in many countries depicting a widening gap between the rich and the poor. For instance, overall poverty and food poverty in the Gambia have both increased from 60 percent and 33 percent in 1990 to 69 percent and 37 percent in 2000, respectively. During the same period, the proportion of food insecure has risen from 15 percent to 21 percent. In Senegal, the number of poor people increased from 33 percent in 1991 to 65 percent in 1995. The Situation in Chad is similar if not worse. By comparison, Cape Verde and Mauritania can stand as success stories and have made decent progress towards meeting a few goals. However, they are also off track when it comes to the overarching issue of poverty reduction. All these countries recognise drought and climate variability as one of the major obstacles to sustainable development. Table 3 gives a summary on how climate change could influence the achievement of the MDGs even if the relationship seems to be more direct with some goals than with others.

Table 3. Potential impacts of climate change on the MDGs at the local and national level

	Local level	National level
Goal 1	1. Agricultural production altered 2. Degradation of the productive base 3. Rural poverty increased 4. Local food security threatened	1. Economic growth impeded; 2. Loss of foreign exchange through reduced exports and increased imports of food commodities 3. Poverty reduction efforts stalled 4. National food security threatened

Goal 2	Primary education may be indirectly affected by climate change through: (1) lack of money to pay school fees; (2) use of child labour in search for survival; (3) hunger and illness; (4) displacement and migration; (5) abandonment of children	Sluggish economic growth and expenses on relief activities may prevent governments from investing in new educational facilities, maintain existing infrastructures and employ/pay teachers
	Local level	National level
Goal 3	1. Girl education may be affected by poverty since many parents will chose to educate boys in case of limited resources 2. Survival activities puts more pressure on women removing them from income generating and power brokering activities	The poor state of the economy can reduce activities and programmes geared at the promotion of women and undermine efforts for their empowerment
Goal 4	Climate change is likely to increase malnutrition, infectious and diarrhoeal diseases, which will exert a heavy toll on children	
Goal 5	In the advent of climate change, maternal health may be affected by (1) drudgery related to survival activities; (2) poor nutrition due food shortages and (3) higher exposure to vector-and water-borne diseases	Limited national resources may (1) limit investment in health facilities, vaccines, child nutrition and HIV/AIDS campaigns; (2) increase the risk of loosing qualified medical personal due to poor working conditions
Goal 6	1. The prevalence of vector-borne diseases such as malaria may increase because of the changing climatic conditions 2. The prevalence of water-borne diseases may increase because of deterioration of water resources	
Goal 7	(1). Climate change in the Sahel will exacerbate land degradation and desertification, worsen water scarcity and erode biological diversity. (2). Failure of agriculture will push people to engage in activities such as overstocking/overgrazing and uncontrolled sale of firewood and charcoal which are not compatible with environmental sustainability (3) Environmental problems in urban centres will be aggravated because of overcrowding	Degradation of environmental conditions due to climate change will be a major blow for the sustainable development of the Sahelian nations

4.4. Summary

The Sahel region has severely suffered from climate variability and could suffer even more in the future because of climate change. However, one important lesson the international community may have learnt from the tragedy of the Sahelian crisis is that it had perhaps more to do with general lack of preparedness than the declining rainfall per se. The fifteen years preceding the beginning of the drying were characterized by abundant rainfall, which encouraged many of the colonial powers first and then the freshly independent African states to make heavy investments on export agriculture at the expense of the cereal crops (maize, millet, sorghum), which constituted the food base of the rural communities (Batterbury, 2001; Mortimore and Adams, 2001). This translated into what was known as the cotton and groundnut boom of the 1950s and 1960s. So when drought occurred abruptly (there was no early warning systems), neither the resource-poor population of the Sahel, individual governments, nor the international community were prepared to cope with the situation in the short run.

The Sahelian countries, like other developing nations, have embarked in the battle to halve the number of extremely poor and hungry by 2015 and meet other development objectives. For most of these countries, achieving the MDGs is already a daunting challenge under current conditions. Climate change will make the task a 'mission impossible' unless drastic measures are taken immediately. Interestingly though, if these goals came to be achieved against the odds, vulnerability will be reduced in a significant manner and the Sahelian populations will be better prepared to cope with the negative effects of future climate change.

5. Adaptation to climate variability

The negative effects of the 1970s droughts, which led to dramatic losses of human lives and visited hunger and abject poverty on millions of Sahelians was exacerbated by the fact that the coping capacity of the rural populations was stretched to its limit and therefore became inadequate to respond to the 'crisis' (Hulme, 2001). Inevitably, the constantly declining and irregular rainfall during that dry episode was going to affect the economies and societies of the Sahel, which were (and are still) primarily based on agriculture and other forms of natural resource use. But certainly, it did not have to wreak damage of that magnitude had farmers enjoyed more diverse livelihood systems, or owned sufficient assets, or if they could resort to supplemental irrigation, adapted crop varieties and adequate soil and water conservation techniques. For example, climatologically speaking, the 1984 drought was more severe than that of 1973. Yet, it made relatively less damage as the economies and the societies of the Sahelian countries had, by the mid-1980s, developed more appropriate coping mechanisms to tackle such extreme situations (Batterbury, 2001).

5.1. Institutional framework

The Sahelian states recognised the utter importance of combating drought in their food security and sustainable development policies, way before climate change came to the limelight of international debate. This culminated in the creation of the CILSS in 1973. Its mandate, '*to invest into the research for food security and in the fight against the effects of drought and desertification in order to achieve a new ecological equilibrium*' in the Sahel (CILSS, 2004) bears testimony to the commitment by the Sahelian governments to address the pressing issue of climate-related food insecurity in the region.

The commitment of the Sahel region to tackle environmental problems including climate change was reiterated with the ratification by the various states of the three major international conventions namely the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD) and the UNFCCC. Three countries in the region, namely Gambia, Mali and Senegal, have so far ratified the Kyoto Protocol to the UNFCCC. In an effort to implement the Climate Convention, the Sahelian countries have produced and submitted their initial NCs to UNFCCC Secretariat. Mauritania has already finalised and submitted its NAPA for review and for the other countries the process is well under way.

5.2. Impacts and adaptation studies in the initial NCs

The analysis of the NCs provides insights on the perception the various Sahelian nations have of climate change, its impacts and the adaptive strategies and measures they plan to put in place to mitigate or take advantage of those impacts. Except Guinea Bissau whose initial NC was not available when this report was being prepared, all countries have submitted their initial NCs to the UNFCCC Secretariat. Unsurprisingly, the NCs put a strong focus on agriculture in their vulnerability and adaptation studies given (1) the role of this sector in people's livelihood systems and in the economies of these countries and (2) the fact that agriculture is among the most vulnerable sectors to climate change.

5.2.1. Burkina Faso

In its vulnerability and adaptation analysis, the government of Burkina Faso chose the 1961–1995 period as baseline and focused on the cotton sub-sector. Using the climate model from the Meteorological Research Institute (MRI) of the Japanese Meteorological Agency (JMA), temperatures are shown to rise by 2.5 degree C and rainfall to slightly increase in the cotton producing area in the advent of climate change. However, inter-annual variability in precipitation will be more pronounced (standard deviation of 180mm). Overall, national cotton production is predicted to increase due to expanded cultivated area, better water availability and improved technologies. Among other adaptive measures, Burkina Faso considers:

- a diversification of crop production with the promotion of fruit and vegetable crops;
- the use of varieties of different cycles;
- effective soil and water conservation techniques;
- the use of agro-meteorological data in the promotion of agricultural technologies.

5.2.2. Cape Verde

A reduction in annual rainfall (-20 to -10 percent), combined with rising temperatures of up to 2.5 degree C, will expose a large proportion of the rural people to food insecurity. Cultivation of maize, the major staple food crop, under rainfed conditions will no longer be feasible in many areas. To adapt to these changes, Cape Verde suggests:

- agricultural diversification and increased use of more drought adapted crops;
- water harvesting techniques and supplemental irrigation;
- use of drip irrigation for a more effective use of irrigation water;
- development of livestock farming where maize will no longer be suitable;
- promotion of leguminous and fodder crops to improve soil conditions and animal productivity.

5.2.3. Chad

Temperatures are projected to increase by between 0.6 and 1.7 degree C towards 2023, depending on the model used, the GHG emission scenario and the location considered within the country. Rainfall will remain at current levels or increase slightly. However, the temporal distribution of the rains will be altered, with more rain falling at the onset of the growing season and less rainfall in the normally more rainy months of July, August and September, which can negatively affect crop development. In addition, increased evapo-transpiration as a result of the warming will exacerbate the arid conditions and negatively impact forest, agricultural and water resources.

Chad put a great emphasis on soil conservation techniques including agroforestry as part of the options for adapting to present and future climate change:

- Hedgerow intercropping: this agroforestry technology is popular in the densely cultivated and degraded areas such as the Tchanar region in the southern part of the country;
- Live hedges: agroforestry research has shown that several local shrubs (Acacia ataxacantha, A. nilotica, A. tomentosa, Bauhinia rufescens, Parkinsonia aculeata, Prosopis juliflora, Ziziphus mauritiana) have potential for live hedge technology;
- Improved fallow: many herbaceous legumes such as Dolichos lablab, Mucuna pruriensis, Vigna unguiculata (fodder cowpea), Stylosanthes hamata, Calopogonium mucunoides can be used. A cereal yield increase of 15–25 percent has been observed after C. mucunoides;
- Compost and manure: have the potential to increase sorghum (the major food crop) and cotton (the major cash crop) yields, which currently stand at about 0.6 tonnes per hectare;
- Other industrial crops, which are less sensitive to water stress than cotton. With a hotter climate and no major increase in rainfall, many cotton producing areas will cease to be suitable for the crop and irrigation will be too costly for cotton producers to be considered as an option;
- Improved fodder production: free grazing, albeit a sensible adaptation strategy in the past, is unsustainable. The promotion of fodder crops such as Stylosanthes hamata and Vigna unguiculata will have to be considered. In the short term, the use of spatial techniques (remote sensing and GIS) to demarcate grazing areas is necessary to quell agriculturist–pastoralist conflicts.

5.2.4. The Gambia

The government of the Gambia used the 1950–1990 period as baseline. In general mean temperature is projected to rise by 3 to 4.5 degree C in the 2075 horizon. For the vulnerability assessment, the agricultural sector has been divided into 4 sub-sectors and modelling exercises carried out for each of them:

Maize system: for rainfall, some GCM models show a decrease of (-59 to -15 percent) while others show an increase of 15 to 29 percent by 2100. In general, increased runoff (58–98 percent) and drainage (48–84 percent) are expected. Total maize biomass production is likely to decrease by 19 to 35 percent compared to baseline even in the case of increased rainfall due to massive leaching of nitrogen.

Late millet system: rainfall is expected to increase by 28–69 percent depending on GCM outputs. Runoff (2–26 percent), drainage (3–31 percent) and extractable water (9–36 percent) will also increase. A total biomass decrease of 25 to 44 percent is expected.

Early millet system: a 5–59 percent increase in rainfall is expected inducing an increase in runoff (8–56 percent), drainage (4–57 percent) and extractable water (4–30 percent). Total early millet biomass will decrease by 1 to 21 percent.

Groundnut system: rainfall is expected to increase by 13–25 percent, runoff by 8–23 percent and drainage by 9–21 percent. A higher nitrogen uptake is expected resulting in a total biomass increase of 15–47 percent compared to a situation without climate change.

The adaptation measures the Gambia considers include:

- develop and promote drought, pest and disease, weed, salinity resistant and high yielding crop varieties for the local conditions;
- enhance and maintain soil fertility to improve the efficiency of water consumption for agriculture;
- change of planting dates and substitution of long duration upland and lowland crop varieties for short duration varieties;
- more use of sprinkler and drip irrigation;
- integrated agricultural management system;
- development of early warning systems to inform farmers and other stakeholders;
- promotion of post-harvest technologies to reduce losses in the field and during storage. This has a long term effect of reducing cultivation of marginal lands.

5.2.5. Mali

Climate change is expected to have drastic consequences in Mali. The drying trend that has already been going on for the last few decades will be exacerbated with the following consequences:

- reduction in cereal yield due to drought and declining soil fertility;
- reduction of livestock numbers due to the shrinking of grazing areas;
- reduction of fauna and fishing resources;
- expansion of cultivated areas to compensate for low yields with encroachment in low potential areas.

Vulnerability and adaptation studies have been carried out on the cereal crops, mainly sorghum. Different temperature rise scenarios (1degee C, 2 degree C, 3 degree C, 4 degree C), coupled with rainfall reduction in relation to the 1961–1990 period, have been used to predict the behaviour of sorghum crop at the 2025 horizon. The results show that sorghum yield will drop by 2–26 percent depending on the scenario and model considered. To adapt to the changing climate conditions, the government of Mali focuses its adaptation strategies on two major aspects:

- agro-hydro-meteorological survey of crops and pastures with a view to develop early warning systems;
- agro-meteorological assistance to the rural population by providing timely information on weather and useful advise for coping with different scenarios.

5.2.6. Mauritania

GCM models show that temperatures could rise by up to 1–2 degree C. Rainfall is expected to decline by 15–30 percent in the South and 2 percent in the North with the high warming scenario. In the low warming scenario, rainfall reduction will be less than that without climate change. The vulnerability assessment and adaptation exercise of Mauritania focused on the cereal producing area in the Brakna region, where millet and sorghum are the major crops. Since 1971, the area has experienced declining annual rainfall, a higher frequency of dry spells and higher evaporation rates due to rising temperatures. It is understood that climate change will significantly reduce the area suitable for cultivation as well as cereal yields, which will exacerbate food insecurity and poverty. The current adaptation strategies proposed by the government of Mauritania are:

- construction of dams and dykes to limit water losses, control erosion and increase areas for horticulture
- intercropping leguminous crops (cowpea) and water melon with millet and sorghum to improve soil fertility and diversify production
- encourage consumption of imported wheat and rice to orient cereal production towards irrigated crops, which are less dependent on rainfall
- restoration of wetlands (Aleg and Mâle lakes) for a better management of natural resources and biodiversity conservation

The government of Mauritania has also developed a number of important projects to tackle the threat of future climate change:

- Construction and rehabilitation of dams and dykes (US $ 300 million)
- Development of irrigation in the water retention areas (US $ 200 million)
- Protection and restoration of humid zones (US $ 250 million)

5.2.7. Niger

Niger chose the 1961–1990 period as baseline and projects a rainfall decrease of 10–20 percent by 2025. The vulnerability assessment was carried out in the food crop system dominated by millet and sorghum, which make 85 percent of production and provide for 80–90 percent of the energetic needs of the population. The major agricultural areas are Dosso, Maradi and Zinder. Niger considers that the drying conditions from the early 1970s are part of climate change and that future changes will aggravate the current situation. Niger identifies these processes as consequences of climate change:

- a doubling of cultivated areas within a generation (without increase in per capita production) with agricultural production encroaching into the marginal areas in the north at the expense of sylvo-pastoral systems;
- exacerbation of agriculturist–pastoralist conflicts;
- degradation of land resources (physical degradation and loss of fertility);
- reduction of plant and animal biodiversity;
- perturbation of hydrological regimes;
- sand invasion and saline intrusion in some areas;

- intensification of migration

Some of the adaptation measures suggested by Niger include:

- development of seasonal forecast and EWS for farmers;
- readjustment of sowing dates;
- drought resistant varieties;
- irrigation and fertilisation, and more appropriate use of land resources;
- development of techniques for storing food and seed stocks;
- strengthen research to develop more vigorous varieties that are highly productive and resistant to drought, pests and diseases
- management of pastures, artificial insemination, use of EWS to warn pastoralists of impending fodder shortage

5.2.8. Senegal

Senegal based its projections on a 20% reduction in rainfall and a 4°C increase in temperatures, choosing 1961–1990 as baseline. Climate change will thus result in a reduction of potential millet yield (-33 to -25%) and a reduction of the area suitable for the crop. In comparison, the 1972 and 1973 droughts reduced potential yields by 79 to 63% respectively. Under current conditions, a modelling exercise has shown that moderate intensification and slight expansion of agricultural areas can meet the cereal needs of the population and even produce surpluses. With climate change, coverage of food needs will worsen by 38 to 11% in relation to the current situation, exposing an additional 1–4 million people to food insecurity by 2050.

To remedy this situation, Senegal considers these strategies:

- improvement of soil fertility with judicious use of organic and mineral fertilisers;
- the practice of fallows;
- promotion of adapted varieties;
- improve the efficiency of irrigation systems;
- improve cropping techniques and pest management;
- development of research for the improvement of cropping techniques and genetic material;
- research on induced-rainfall mechanisms

5.3. Critical analysis of the initial NCs

The earlier understanding of climate change as a future problem certainly influenced the structure of the initial NCs. Indeed, these are strongly skewed towards inventories of GHG sources/sinks leaving little space for vulnerability and adaptation studies. For example, Burkina Faso focused on the high potential cotton production area in the west yet the drier eastern part of the country concentrates the poorest and most vulnerable people. Even if cotton is the number one foreign currency earner for the country, studying the impacts of climate change on food crops and subsistence farming communities would probably be more relevant in terms of food security and poverty reduction.

The vulnerability and adaptation studies also suffered from a number of other limitations including the lack of appropriate models, coarse resolutions and the unavailability of long-term qualitative and quantitative data. For instance, in the case of Niger, the low level of variation showed by the GCM outputs (4 percent reduction in rainfall by 2025 in relation to the 1961–1990 baseline period) was not convincing enough. Thus, a new baseline period (1968–1997) was defined and a 10–20 percent rainfall reduction and a 10–20 percent temperature rise by 2025 assumed. While the level of rainfall decrease may be sensible, a 10–20 percent rise in temperature relative to the 1968–1997 period (an already hot period) seems unrealistic. The same can be said of Senegal, where the 4 degree C increase in mean temperature relative to the 1961–1990 average assumed seems unlikely. This, and the sometimes conflicting outputs showed by the various models and scenarios, makes some of the predictions highly uncertain. Another element of criticism in relation to the vulnerability/adaptation studies is that none of the models considered the effect of higher atmospheric CO_2 and that of its interactions with temperatures and precipitations on plant productivity. Finally, the failure of the modelling exercise to factor in socio-economic data means that all the outputs translate worst case scenario impacts of climate change on the agricultural sector. Therefore, the studies presented in the initial NCs can be seen as impact assessments rather than vulnerability assessments.

These and other shortcomings should be addressed in the second NCs, which are in preparation for the majority of countries. For example Senegal, which has already finalised it second NC, carried out its vulnerability and adaptation study choosing more realistic warming scenarios and including a higher number of agricultural systems. However, the NAPA process certainly provides a much more conducive framework to carry out comprehensive vulnerability and adaptation studies and to rectify some of the weaknesses of the NCs for the Sahelian countries.

6. Analysis of the adaptive resources in the Sahel

Improving the resilience of natural and managed systems (and hence that of the communities that depend on them for their livelihood) is a crucial feature in the fight against drought or other climatic hazards. In the Sahel, many programmes and projects have explored (with some degree of success) a wide range of adaptive options, supported by the international community and involving strategic partnerships between national and international research systems, NGOs, development agencies and local organizations. It is becoming increasingly clear, however, that if the battle of adaptation to climate change is to be successful, development policies cannot afford to be overly interventionist or 'top down'. The traditional diagnostic–prescription, which has for so long been the modus operandi of rural development planning will not work (Mortimore and Adams, 2001; Marcussen, 2004).

Technological innovations, be it through breeding and release of early-maturing or drought-tolerant cultivars, soil and water conservation or agroforestry, for example, will be necessary of course, aided by improvements in weather forecasting. However, these technologies are not likely to meet with success if they are packaged to the farmers as the panacea destined to put an end to their predicament. Drought (or rainfall variability, to be more correct) is nothing new to dryland dwellers. The farmers of the Sahel, just like their counterparts from other semi-arid regions of the world, have survived thanks to their capacity to adjust to these climatic uncertainties. Therefore, the internal adaptive resources of these farmers cannot be overlooked. The success of any interventions aimed at helping the Sahelian farmers in their day to day battle against climatic risks will have to be based on: 1) a careful assessment of farmers' adaptive resources to determine their forms, their strengths and their limitations; and 2) a subtle blending of this indigenous knowledge with what has to be offered in terms of scientific and technological innovations.

6.1. Indigenous responses to climate variability

The northern part of Nigeria, which was badly hit during the desiccation years, has been a fertile ground for some socio-economic and anthropological studies investigating the vulnerability and adaptive capacities of the Sahelian farming communities (Adams and Mortimore, 1997; Mortmimore and Adams, 1999; Mortimore and Adams, 2001). These authors identified 5 categories of crisis and described some elements of strategic adaptation farmers have relied upon in response to these crises (Table 3). One important aspect of the farmers' survival strategies in the Sahel resides in their ability to 'negotiate the rain', which goes beyond the simple objective of managing a drought event. Owing to the inter-annual variability of rainfall, farmers have to show enough wits and flexibility every year in the timing of the various farming operations (clearing, planting, weeding and harvesting) and in the management of household labour. They use a combination of local climate indicators including tree fruit and flower production, duration and intensity of cold and hot periods, bird and insect behaviour, movement of stars and the moon to predict precipitations (Roncoli et al., 2002). For example, in a good rainfall year, farm households, which are limited by labour, may decide to reduce the cultivated area, use more manure and focus on weeding to maximise yield while households that have more labour can expand the cultivated area to make maximum use of good rainfall conditions. In a drier year, the behaviour of both sets of households would be different.

Table 3. Crises and farmers' strategic adaptations in the Sahel (Mortimore and Adams, 1999)

Perceptions of 'crisis'	Strategic adaptations by farmers
A drought crisis	Negotiating the rains
A food crisis	Managing biodiversity
A stocking crisis	Integrating animals
A degradational crisis	Working the land harder
A coping crisis	Diversifying livelihoods

Maintaining a high level of plant biodiversity within the farm boundaries and in the agricultural landscapes has also been a recognised strategy to reduce food insecurity. Simultaneous growing, mixing or intercropping different types of crops (or cultivars of the same crops) is not uncommon in northern Nigeria and in many other areas of the Sahel. This strategy seeks to avoid risks of total crop failure rather than maximising yields of a particular crop. Despite the dry conditions, inventories have shown a surprisingly high number of non-domesticated species (trees, shrubs, herbs) in the Sahelian landscapes, each of them playing useful roles. The unrelenting conversion of natural systems to croplands is no doubt reducing the plant populations, but plant diversity is not as significantly affected as one would expect since many indigenous tree species are well conserved through a system of selective clearing. The tradition of maintaining or nurturing key useful tree species on farmlands (the parkland farming systems) is a well established feature of the Sahelian farming systems. This practice not only helps conserve biodiversity but also buffers against production risks. While harvesting food, medicine, fodder, resins and building material from these multipurpose trees is a normal occurrence (Joet et al., 1998; Ong and Leakey, 1999), the farmers' reliance on indigenous trees becomes more important during times of acute food shortages (Mortimore and Adams, 2001).

The internal capacity of the rural populace to innovate and readjust their farming systems in the face of adverse conditions has also been demonstrated in the Senegalese groundnut basin. In the 1980s, the Sahel drought was at its peak, but this also coincided with a period of important political reforms in the agricultural sector. The New Agricultural Policy (NPA) was brutally put into effect as part of the structural adjustment programs (SAPs) prescribed by the donor community and the international financial institutions. The subsequent removal of government subsidies on agricultural inputs such as seeds and fertilisers had disastrous consequences on the groundnut industry, which had provided a lifeline to the farming communities for several decades. One way in which farmers responded to the crisis (the demise of the groundnut industry) was to introduce the cultivation of water melon. Before 1987, hardly a farmer in Senegal grew water melon, but by 1999, national production reached almost 300,000 tonnes (Figure 6). Yet, involvement from the governmental agricultural services in this transformation was minimal. This happened virtually through a process of passive farmer-to-farmer dissemination, fuelled by the high demand in the local market. The water melon crop spread rapidly within the farming communities thanks to its high drought tolerance, its earliness (it matures before the traditional crops) and its capacity to produce in years where many other crops fail.

The study of the dynamics of land use in the village territory of Yomboli, northern Burkina Faso, between 1945 and 1991, provides another example of strategic adaptation by farmers when confronted with changing climatic conditions (Reenberg et al., 1998; Reenberg, 2001). The combined use of aerial photos, satellite imagery and GPS measurements has helped to detect the gradual shift that has occurred in the agricultural landscape. Until 1945, crop production was almost exclusively concentrated on the pediplains (more fertile and finer-textured soils). When the climate was becoming increasingly dry in the following decades, farmers progressively abandoned the pediplains and moved to the dunes. Further investigation showed that this shift from fertile to more sandy soils has been triggered, not by declining soil fertility as many tended to believe, but rather by the farmers realising that the reduced rainfall no longer allows sufficient yields from these finer textured soils (Mazzucato and Niemeijer, 2000; Reenberg, 2001). Farmers understood the disadvantage of heavy soils in drought years and therefore, where land availability allowed it, field reallocation has been used as a strategic response to reduced rainfall. However, since 1991 (rainfall had come back to near long-term average) the Yomboli farmers have been diversifying cultivation and dispersing their fields on both soil types to reduce the risk associated with variability in precipitation. This risk-spreading strategy has also been observed in other areas of the Sahel such as the Fandou Béri in Niger (Warren, 2002).

These few illustrations represent but a small portion of the myriad adaptive strategies of the Sahelian farmers. Nonetheless, they give an idea of the flexibility of rural households vis-à-vis the management of their agricultural and natural resources. Obviously, these strategies have their own strengths and have helped rural dwellers withstand some of the pressure posed by climatic variability. However, they also have their limits, especially when weather extremes become more persistent leading to so-called entitlement failure (inability to command sufficient food to prevent starvation) (Sen, 1981). Moreover, adaptation to changes including climate variability is a dynamic process and should, as a survival mechanism, display enough flexibility to accommodate new components. The need for alternative sources of income outside agriculture is real and calls for a diversification of livelihood strategies, which starts usually with livestock ownership (Figure 7). Keeping animals has become an important aspect of the farmers' livelihoods in the Sahel. Recent surveys show that the number of animals kept by sedentary farmers is increasing and indeed has become more important than the number held by the specialised nomadic pastoralists. A progressive shift from cattle to small ruminants has also been observed, which can be viewed as a strategic move since small stock reproduce much faster than cattle and are more hardy, less costly and easier to feed (Mortimore and Adams, 2001).

As part of a wider economy, farmers are aware of (and indeed are grasping) the other income-generating opportunities existing around them, which can help supplement their farm-derived income. These vary from small trade and business activities within the confines of the village territory, to seasonal migration or travel to distant places (Batterbury, 2001; Mortimore and Adams, 2001). Thanks to the rapid urbanisation and improved mobility in west Africa, farmers are now able to export their labour force towards the cities, neighbouring coastal countries or even to other continents to earn a living (Raynaut, 2001). In many cases, seasonal migration offers rural cultivators an opportunity to improve farm productivity, not only by investing part of their remittances in the farm, but also by applying technologies 'borrowed' from elsewhere, as for example when returning emigrants in Burkina Faso innovate by using farming practices learnt from neighbouring Côte d'Ivoire (Batterbury, 2004).

6.2. National efforts to reduce vulnerability of the agricultural sector

The Sahelian countries put agriculture at the core of their socio-economic development and the fight against extreme poverty. This sector plays many important roles including: (1) improvement of food security; (2) job creation and income for the rural population; (3) supply of raw material to agro-industries (peanuts and cotton, for example); (4) the absorption of a part of the industrial and semi-industrial sector's outputs (fertilisers, pesticides, machinery, etc); and (5) the generation of foreign exchange. A whole range of development plans, programmes, policies and projects have been developed by the Sahelian nations and most of them contain provisions for improving agricultural productivity. Policy documents such the National Environmental Action Plans (NEAPs), the National Action Plans to Combat Desertification

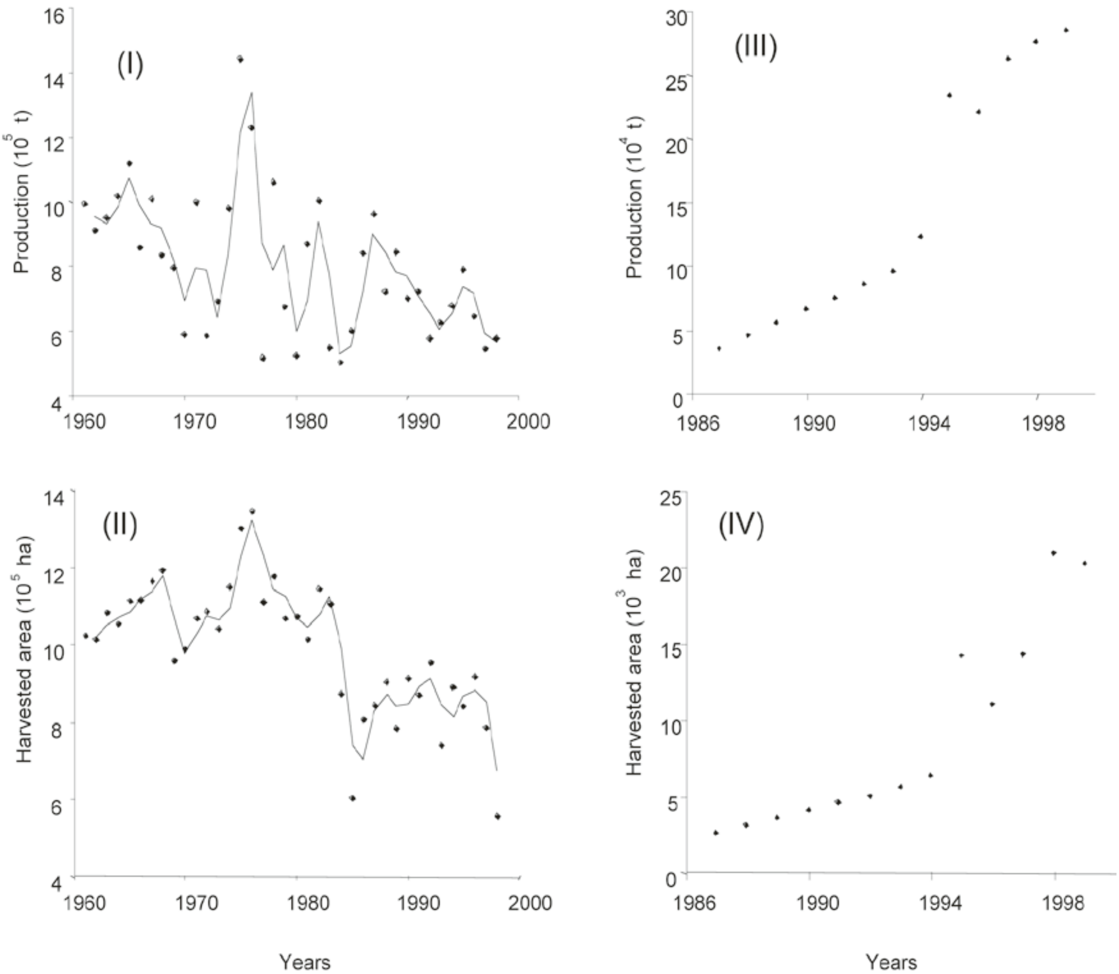

Figure 6. Trends of groundnut production (I and II) against water melon production (III and IV) in Senegal (data from FAO-STAT).

(NAPs), the Poverty Reduction Strategy Papers (PRSPs) and many other sectoral plans contain strategies and interventions aimed at accelerating agricultural growth as an engine of economic development and poverty reduction. Although the issue of climate change is not often addressed directly in these policies and programmes, climate variability (especially drought) is often recognised as the major problem to which responses need to be found if food insecurity and poverty have to be significantly reduced in the Sahelian countries. Implementing these strategies can contribute meaningfully to reducing the vulnerability of the rural populations in the face of climate change.

There is a great emphasis on the need to increase agricultural output and its share in the national GDPs. For example in its poverty reduction strategy, Burkina Faso envisions to expand agricultural output by 5–10 percent by 2010 and to increase the income of farmers and breeders by at least 3 percent a year. The objective of boosting agricultural production is to mitigate food insecurity and foster income generation through the promotion of agricultural exports. Policies are being put in place in all the CILSS member countries to diversify their agricultural economies away from the traditional export crops such as groundnut and cotton by initiating research and development into non-traditional agricultural commodities. Horticulture is emerging as one of the most promising tools to reduce poverty in rural areas. In Senegal, this sub-sector created 6000 jobs in 2000/2001 of which 72 percent were in rural areas and 60 percent filled by women.

Measures undertaken to reduce the excessive dependency on rainfall include the development of irrigation schemes in suitable areas (depressions and wetlands, plains, plots on the village perimeters) and the promotion of rural hydraulic engineering through the drilling of wells and the building of reservoirs and water retention basins. Several countries including Cape Verde and Mauritania have experimented with micro-irrigation techniques and are projecting to scale up the technology along with improved varieties and the exploration of niches for the production of high value crops. Burkina Faso has valuable experience in rain induction using the cloud seeding technique. In 2002, the year the program was put into effect for the first time, rainfall was extended until September. Agricultural output increased by 547,000 tonnes. Cereal production in 2002/2003 reached 3,119,100 tonnes i.e. 22 percent higher than the average of the 5 previous crops.

Significant efforts are also being made in the management of soil fertility and restoration of degraded land, which are critical for a sustainable agricultural production. For instance, in June 2001 an operation to build 50,000 manure pits was launched in Burkina Faso and nearly 52,454 pits were materialised, which represents a 115 percent achievement rate. During the National Farmers Day in December 2002, which corresponded to the beginning of the implementation of the Integrated Soil Fertility Management Plan (PAGIFS), farmers agreed to a target of 200,000 pits in the 2003/2004 crop year. Apart from that, the construction of an extra 71,148 pits, zai-hole tilling of 29,793 hectares and mulching of 16,000 ha have been achieved through normal extension work. These efforts were supported by the government with the purchase and distribution of fertilisers and improved seeds to poor farmers. Wildfire committees have been instituted in 4 pilot regions to protect natural resources and 66,500 ha of degraded land have been re-afforested. In Niger, mechanical anti-erosive structures have been established on 50,628 hectares and biological installation on 4,550 ha in addition to the 1,500 km of linear plantings (windbreaks and field borders) and the 5,000 ha of plantings on restricted areas. Between 2000 and 2002, some 7, 272 km of fire breaks were installed. To safeguard grassland ecosystems, 37,120 km of fire breaks were inspected and 913 fire rangers trained.

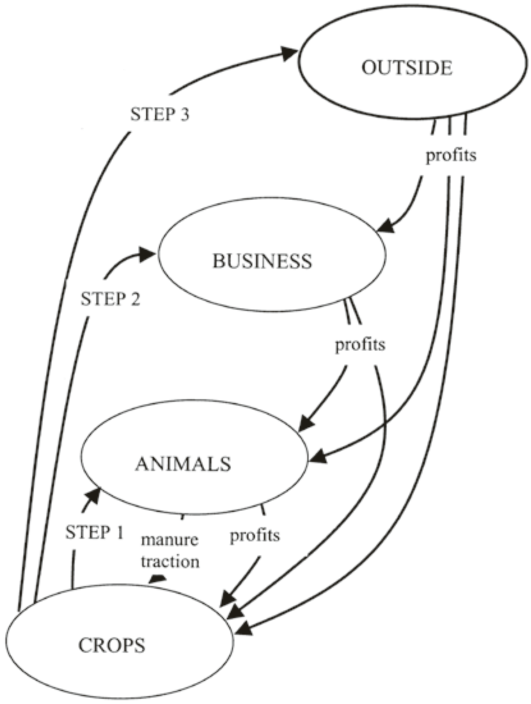

Figure 7. A simple model of diversification in the rural household economy (adapted from Mortimore and Williams, 1999)

Modernising the livestock sub-sector is another useful step to mitigate environmental degradation and improve rural income. Important artificial insemination programs are underway to improve the meat and milk yield of the local races. In 2002, Burkina Faso produced 1000 doses of bovine semen, distributed more than 50 breeding cattle (Azawak zebu) to breeders, imported 140 heads of Gyr and Gyrolando cattle from Brazil, opened the National Livestock and Genetic Improvement Centre and increased support for the practice of cattle and sheep fattening. To tackle the issue of fodder shortage during dry season, fodder harvesting and storage techniques are being promoted together with the introduction of fodder crops in many countries. More attention is also being directed to the improvement of animal health with the creation of veterinary posts together with the establishment of water points and the delimitation of pasture lands and cattle trails.

6.3. The potential role of research in climate change adaptation

6.3.1. Climate research

6.3.1.1. Recent developments on the Sahelian climate

The quest for an explanation to the Sahel drying has engendered the emergence of two lines of thought. There are the proponents of the feedback (between atmospheric circulation and land surface processes) hypothesis. The feedback mechanism is one of the earliest attempts at an explanation brought forward as a response to the drought of the 1970s (see Hulme, 2001) and was strongly promoted by the pioneering climate modelling work of Charney (1975). Under this paradigm, changes in land use and/or land cover are believed to be the major cause of climate perturbations in the Sahel (Douville et al., 2000; Douville, 2001). More recent subscribers to this theory and who took the discussion further, include Diedhiou and Mahfouf (1996), Xue (1997), Zeng and colleagues (1999), Douville and colleagues (2000), Taylor (2001).

Another theory (Rowell et al., 1995; Chang et al., 1997; Nicholson and Kim, 1997) favours the pathway of remote forcing (through ocean–atmosphere interaction) as the most plausible mechanism influencing the Sahel monsoon rains. Some of these studies suggest the existence of a strong link between the variability in the Sahel rainfall and anomalies in the tropical Atlantic sea surface temperature (SST). Others refer to an association with the El Niño Southern Oscillation (ENSO). It seems, however, that SST anomalies explain the low-frequency (decadal) variability of the Sahelian monsoon rainfall better than the inter-annual (high-frequency) variability (Fontaine et al., 1999; Garric et al., 2002). More recently, the remote forcing theory received a major boost from the work of Giannini and colleagues (2003), which brought additional substance to the thesis according to which SSTs are the most powerful indicators of precipitation in the Sahel. Their study shows a good correlation (0.60) between the observed and the modelled times series of July–September rainfall and highlights the strong interdecadal variation in rainfall (Figure 7). More importantly, the contrast between the wetter-than-average 1950s and the progressively drier decades of 1960s, 1970s and 1980s has been successfully reproduced by the model. The authors also confirmed that tropical Pacific surface temperature variation, such as that occurring with the ENSO phenomenon, has an effect on the inter-annual rainfall variation, while the Indian Ocean (and possibly the Atlantic Ocean) affects longer term trends. Although land surface factors feed back into the climate system of the Sahel, they are considered as the consequence, but not the cause, of variability in precipitation (Giannini et al. 2003).

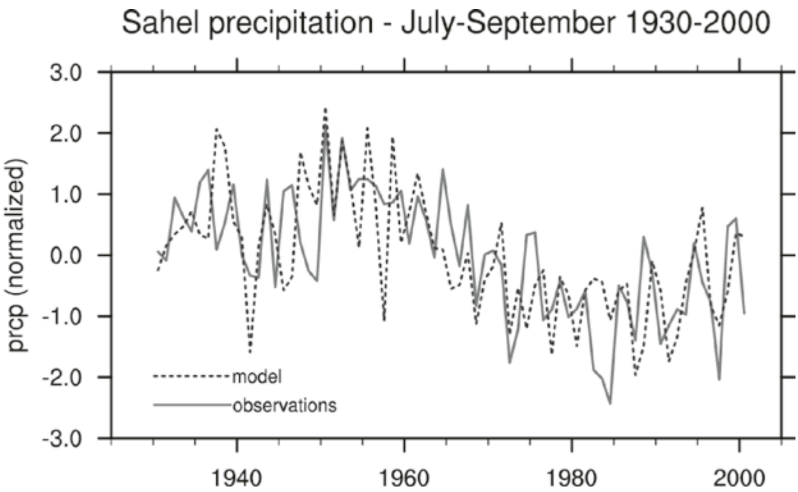

Figure 8. Indices of Sahel rainfall variability: observations used the average of stations between 10°N and 20°N, 20°W and 40°E. Model numbers were based on the ensemble-mean average of gridboxes between 10°N and 20°N, 20°Wand 35°E. The correlation between observed and modelled indices of (JAS) rainfall over 1930–2000 is 0.60. (Time series are standardized to allow for an immediate comparison, because variability in the ensemble mean is muted in comparison to the single observed realization. The ratio of observed to ensemble-mean standard deviations in the Sahel is 4).

6.3.1.2. Climate forecasting for the Sahel region

Predicting future changes in climatic variables such mean temperatures and precipitations is useful for long-term planning. However, predicting the inter-annual and inter-seasonal variation in rainfall is paramount (even without climate change), and more so with climate change since climatic extremes such as drought are likely to increase in frequency and intensity. The international meteorological community has made important progress in the development of predictive methods for the summer rains in the Sahel region. Leading climate research institutions such as the US Centre for Climate Prediction, the United Kingdom Hadley Meteorological Centre, the European Centre for Medium Range Weather Forecasting and the International Research Institute for Climate Prediction have all developed and transmitted seasonal forecasts to national meteorological services in Africa (Ingram et al., 2002). The African Centre for Meteorological Applications for Development (ACMAD) has also been promoting the application of seasonal forecasts in the region. Seasonal climate forecasts, when combined with remote sensing, can significantly improve early warning systems, which have become a powerful instrument for anticipating on and mitigating the negative effects of climate variability in many areas of the world. The combined analysis of remotely sensed vegetation cover data, rainfall patterns and information from market surveys can be effective for predicting or assessing potential crop loss and animal shortfalls. Such methods have been used by the USAID Famine Early Warning Systems Network (FEWS), which has been instrumental in alerting policymakers and governments to impending food shortage. In the Sahel, food security has improved in a significant manner since the early 1980s, and this has been achieved largely thanks to the Global Information and Early Warning System on food and agriculture of the FAO (FAO/GIEWS) used by the CILSS.

6.3.1.3. Potential of seasonal forecasting for local populations

Seasonal climate forecasting has the potential to help farmers and other agricultural users in their decision making processes. A study by Ingram et al. (2002) in Burkina Faso showed that farmers had a strong interest in receiving forecast information since their traditional systems of predicting rainfall have become unreliable due to 'climate change'. Seasonal forecasts could help them adjust their planting dates and management strategies, choose the suitable crops or crop varieties and make a wide range of agricultural and non-agricultural decisions, based on timely and reliable information on the likely onset and distribution of rains (Table 4). In the Machakos district of Kenya, yield simulations using the APSIM model suggest that average maize production could increase by 61 percent compared to farmers' current practices if farmers accessed climate outlook information and adjusted their farming techniques accordingly (Rao and Okwach, 2005). Awareness over an impending fodder shortage due to drought can help livestock farmers sell animals at good prices and avoid competition for insufficient pasture resources and unnecessary death of animals. Climate forecasts can also influence decisions on alternative livelihood strategies such as seasonal migration and other income generating activities.

Table 4. Potential response strategies that farmers may implement in response to receipt of rainfall forecast of high probability for higher or lower than normal seasonal rainfall and lead-time needed to implement strategies in Burkina Faso (Ingram et al., 2002)

Above normal	Below normal	Month required
		Jan
	Implement soil and water conservation	Jan
	Order less herbicide (cotton)	Feb
1. Agricultural responses	Sell livestock or go on transhumance	May
Clear upland areas for planting	Orient furrows across slope	May
Order less insecticide (cotton)	Plant shorter duration crops/varieties	May
	Plant drought tolerant crops/varieties	May
Orient furrows along slope		
Plant longer duration crops/varieties		May
Plant flood tolerant crops		May
Decide planting sequence based on location and toposequence position	Plant more cereal crops	Jun
Increase area planted in uplands		Jun
Plant more cash crops	Apply less fertiliser or manure	Jul
Decrease total area planted	Store grain stocks	
Apply more fertiliser or manure		
Sell grain stocks during rainy season		
2. Non agricultural responses	Ration food	Jan
Acquire capital to purchase inputs	Increase income-generating enterprises	Jan
	Migrate	Mar
	Purchase or borrow food grain	Apr
	Send younger men abroad to work	Jun

There exist, however, a number of constraints which need to be addressed before the potential of climate forecasts can be fully exploited for the local communities.

First: the regional nature of seasonal forecasts may limit their relevance for planning at the national or local level. Finer-scale forecasts and more fine-tuned early warning systems, accompanied by a rapid delivery of information are needed. High resolution (less than 50km x 50km) regional climate models (RCMs) such as PRUDENCE (Europe), NARCAAP (North America), CERAS (South America) are now emerging and can give much more detailed outputs at a lower scale. The PRECIS (Providing Regional Climates for Impact Studies) regional climate model developed by the Hadley Centre for Climate Prediction is being used in India, China and in the southern African region to generate scenarios. Such models should be extended to other climatically sensitive areas such as the Sahel region.

Second: knowing whether seasonal rainfall will be above or below normal alone will not necessarily make a forecast useful to potential end-users. When farmers of Burkina Faso were asked what they would need in a seasonal forecast, they ranked their priorities as follows: (1) timing of the onset and end of the rainy season; (2) likelihood of dry spells; and (3) total seasonal rainfall (Ingram et al., 2002). It is not directly possible to know whether dry spells will occur or not in a growing season, but models can now predict the number of rainy days with great accuracy (Rao, personal communication). The analysis of the number of (modelled) rainy days against a defined baseline may therefore give an indication on the likely occurrence of dry spells during the growing season.

Third: since forecasts are probabilistic by nature (i.e. based on possibilities of various outcomes), care needs to be taken when delivering output information to avoid 'finger pointing' in case of bad decisions by farmers. The confrontation of forecast outputs with traditional indicators of precipitations, coupled with a sound discussion on the possibilities of different outcomes, is likely to make seasonal forecasts more acceptable by farmers. In Machakos, more than 83 percent of farmers interviewed said that they would base decisions on forecasts if these could be correct in at least 3 out of 5 seasons, which was even below the observed accuracy level of the predictions, which was 80 percent (Rao and Okwach, 2005). It is, however, doubtful whether the Sahelian farmers would be satisfied with the same level of accuracy given the fact that there is only one growing season per year in this area compared to two in Machakos. Whatever the case, a forecast will be meaningful only if it allows enough lead-time for decision making hence the need to balance between accuracy and timeliness (Table 4).

6.3.2. Improved cultivars

6.3.2.1. What has been achieved?

Shift or variability in annual rainfall, increased frequency of dry spells during the growing season, or reduced length of the growing season in the Sahel, have prompted the need to introduce or develop new crop varieties to help stabilise food production. For instance, in the northern part of Senegal, the cowpea landraces, which were very productive until the late 1960s, have become maladaptive in recent years with the reduction of both the annual rainfall and the length of the growing season (Hall et al., 2003). Similar observations were made throughout the Sahel region since all the cultivars available were late-maturing varieties which, presumably, were adapted to the wetter conditions, which prevailed prior to the late 1960s. In the last two decades, several projects have been funded to address these problems. Breeding programs and technological development with the contribution of organisations like the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and the International Institute of Tropical Agriculture (IITA) have permitted the creation of new improved varieties of millet, sorghum and cowpea, which constitute the major staple food in the region.

The Bean/cowpea Collaborative Research Support Project (CRSP) is a good example of such collaborative projects. In the Sahel chapter, a partnership triangle involving the Institut Sénégalais de Recherche Agricole (ISRA), the University of California-Riverside (UC-R) and IITA, has enabled the development, release and adoption of new cowpea varieties adapted to the changed climatic conditions in the region (Hall et al., 2003). The introduction of 'CB5' from California contributed to improve food security for over a million people who were severely affected by the drought in Senegal. An economic study led by UC-R, and conducted between 1985 and 1986 in the framework of the CRSP, estimated that the four-fold increase in cowpea production generated an average gross-value-increase of approximately US$ 35 million each year. A few years later, two new varieties, 'Mouride' and 'Mélakh', were released, and their adoption countrywide contributed to increase the annual national cowpea production by 120 percent during the period 1993–1999 compared to the 1960–1979 baseline period (Cissé et al., 1995).

In the Sudan, the introduction of the CRSP-bred 'Ein El Gazal' produced similar success. Both on-station and on-farm trials showed it to be superior to the local landraces. In a 5-year on-farm trial using 60 farmers in three locations in northern Kordofan, 'Ein El Gazal' produced an average yield of 363 kg per hectare compared with the local landrace, 'Baladi' that produced an average yield of only 85 kg per hectare (Elawad and Hall, 2002; Hall et al, 2003). The popularity of these cultivars among farmers was facilitated by a number of features including adaptation to drought, resistance to several insects and diseases, high yield and earliness. A recent economic impact study estimates the present net benefit of these cowpea varieties in Senegal at about U.S. $19 million. Following this success, the NGO World Vision International has been actively involved in the field testing and promotion of 'Mouride' and 'Mélakh' in many other countries such as Niger, Ghana, Mali and Chad, through the Natural Resource Management Technology Transfer Inter-CRSP Project (Hall et al., 2003).

A large number of new millet and sorghum cultivars have also been released in Africa over the last 20 years. By 2000, ICRISAT had released 96 improved varieties and hybrids (63 for sorghum and 33 for pearl millet). Most of the cultivars that have been promoted in the Sahel are early maturing and are capable of producing more than local landraces in low rainfall years. In 1984 (one of the driest years in the Sahel's recent history), the drought-escaping sorghum variety 'S-35', selected from ICRISAT material, produced twice as much as the local landraces in Northern Cameroon (Ahmed et al., 2000), which facilitated its rapid adoption by farmers. With feeding habits changing due to urbanisation, rice is fast becoming a staple for a growing number of west Africans. To respond to this demand and to reduce over-reliance on rice imports, the West African Rice Development Association (WARDA) has been implementing breeding programmes aimed at developing varieties adapted to the Sahelian conditions. 'Nerica 2' was developed in 1994 and is one such variety; it is adapted to rainfed conditions and said to be significantly earlier (by 30-50 days) and more productive (+ 50 percent) than the traditional varieties. The tolerance of 'Nerica 2' to drought has also been well documented. The Sahel Institute of the CILSS has a rich catalogue of crop varieties, many of them having drought tolerance features (Table 3).

Table 3. List of drought resistant/tolerant varieties on the Sahel Institute (INSAH) seed catalogue

	Origin	Adaptation level	Potential yield (t ha-1)
Millet			
GB 8735	ICRISAT/Sahel	Tolerant	1.9–2
SOSSAT C 88	IER (Mali), ICRISAT	Tolerant	2.5
Cowpea			
TN 88-63	Niger	Good	1–2
TN 5-78	Burkina Faso	Tolerant	0.8–1
KVX 30-309-6G	Burkina Faso	Good	1.5
Maize			
MAKA	Mauritania	Good	3–6
JEKA	Gambia	Tolerant	2–4
Sorghun			
IRAT 204	Senegal	Tolerant	2.4

These new cultivars are being highly appreciated by the rural population because they have a double advantage compared to the local landraces. In a good rainfall year, they can produce food during the hunger period before other crops/varieties reach maturity. These early harvests not only guarantee food to hungry-prone rural families during this most worrisome period, but significantly bolster household income as well, since the market prices are double those received at the end of the season. In addition, early-maturing or drought tolerant varieties can assure minimal production in the case of a drought whereas the use of traditional varieties would lead to certain crop failure. This is a very important aspect from a climate change perspective.

6.3.2.2. Adoption of new varieties

Despite the high number of new varieties released in Africa over the last few decades, studies on adoption are not very common. However, there are some few success stories that are worth mentioning. A good example is the ICRISAT-bred sorghum variety 'S-35' which, officially released in Cameroon in 1986, now occupies about 33 percent of the total rainfed sorghum area of the country and 49 percent in the Mayo Sava region. The same variety was released in Chad in 1989 and now covers 27 percent of the sorghum growing area in the country and 38 percent in Guera region. Compared to farmers' best traditional varieties across all study sites in Cameroon and Chad, S-35 yields 27 percent more output (grain) and reduces unit production costs by 20 percent. These farm-level impacts are larger in Chad where yield gain is 51 percent higher and cost reduction 33 percent higher. The net present value of benefits from 'S-35' research spillover in the African region was estimated to be US$ 15 million and 11 million in Chad and in Cameroon respectively. In Nigeria, the sorghum varieties 'ICSV 400' and 'ICSV 111' are grown in 30 percent of the total sorghum area in the Jigwa region. More information of the adoption and impacts of new varieties can be obtained in the ICRISAT web page: www.icrisat.org. In the Sahelian zone of the Sudan, where the cowpea variety 'Ein El Gazal' was promoted, the first on-station yield trials started in 1983. By 2001, 500 thousand farmers were growing 'Ein El Gazal' and the demand from the Arabian Sudanese Seed Company has kept growing (Elawad and Hall, 2002; Hall et al, 2003).

6.3.2.3. Obstacles to adoption

Efforts to diffuse improved crop varieties in the past have not always been successful. A common problem has been that researchers and farmers may have conflicting objectives: yield improvement in average rainfall years for the former and avoiding total failure in low rainfall years for the latter. The lack of understanding of the manifestation of drought has also resulted in farmers not using new varieties, for instance when early maturing varieties are promoted in places where mid-season drought, not shortening growing seasons, happens to be the problem to address (de Rouw, 2004). Inherently, some drought escaping cultivars developed in the past had a major drawback in that, while they can produce in a short rainy season, they may also yield less than the late maturing varieties in good rainfall years because they do not stay in the field long enough to take full advantage of the rains (Ahmed, 2000). However, this shortcoming can be addressed through plant breeding. For example, the International Maize and Wheat Improvement Centre (CIMMYT) has developed new maize varieties that escape drought but also produce more or as much grain as the late-maturing varieties in good rainfall conditions. Many new varieties have been selected based on the sole criteria of drought tolerance, drought escape or productivity. Thus, failing to consider other aspects that are of interest to farmers and consumers such as taste, nutritional value or resistance to pests and diseases has led to the rejection of some otherwise adapted varieties. In many cases, however, farmers cite inability to access seeds as the major obstacle to the adoption of new varieties (Ahmed, 2000).

6.3.2.4. What is needed?

The tremendous achievements of research partnerships in developing drought-escaping and drought-tolerant cultivars for the major food crops of the Sahel (millet, sorghum and cowpea) needs support by establishing the necessary policy mechanisms that will foster diffusion and adoption by farmers. One critical factor is how to make seeds available to farmers. Given the general failure of the public sector to supply seeds and the lack of interest from private seed companies in open pollinated varieties, new actors such as NGOs and other development agencies have been strongly involved in seed production and delivery. NGOs such as World Vision International, Aquadev (A Belgian NGO), EWA (an Austrian NGO) have been instrumental in promoting the new cowpea varieties in the CRSP project. These NGOs distribute seed to selected individual farmers or farmer-based seed production cooperatives for widescale seed production. While this type of seed delivery scheme has been successful in reaching a large number of farmers, whether it is sustainable or not warrants further studies. Various schemes, involving the public seed sector, NGOs and church organisations are being experimented in Mali. Valuable lessons could be learnt from this kind of experience (see www.

icrisat.org). It is also important that aspects other than drought tolerance and productivity be considered when developing new varieties. These include taste, nutritional value, ease of processing and resistance to storage pests. Genetic engineering is emerging now as a new technology and the opportunities it offers should be explored better to breed more robust cultivars, which could combine drought resistance, productivity and various other desired features that will enhance the acceptability of new varieties among farmers.

6.3.3. Soil and water conservation

6.3.3.1. Short synthesis of the existing knowledge

In the Sahel, 20 to 40 percent of annual rainfall is lost as runoff. This often results in agricultural drought and massive soil erosion in some sites (hillsides, plateau edges) and flooding in others (low lying land, valley bottoms). Agricultural drought is, to a significant extent, responsible for shortfalls in food production in semi-arid areas. Yet, agricultural drought cannot always be linked to low rainfall (meteorological drought). In the Sahel, the loss of rain water through runoff, soil evaporation and drainage below the rooting zone is often considered as the major cause of moisture stress (Zougmoré et al., 2004). Thus, it appears that if rainfall is low and unreliable, capturing the little that falls and making it available to crops could provide an effective and sensible way of improving farm productivity and reducing farmers' vulnerability to agricultural drought. At the same time, improving water infiltration in the uplands and hillsides can reduce flooding in the lower end of the toposequence, i.e., in valley bottoms. This constitutes the very rationale of soil and water conservation (SWC) strategies in the Sahel. The International Network for Research on Drought Resistance (R3S), launched jointly by the Conference of the Agronomic Research Organisations in West and Central Africa (CORAF) and CILSS, has disseminated several SWC techniques in west Africa in collaboration with National Agricultural Research Systems (NARS) and Advanced Research Institutes (ARIs) such as the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) (Ruelle et al., 1990 a, b, c).

There are arguably few places in Africa that have seen more soil and water conservation projects than the Central Plateau of Burkina Faso and the Koutiala region of Mali. In these regions and many others in the Sahel, soil crusting has rendered vast areas of land uncultivable. To those involved in SWC research and development, however, these hardened soils represent some 'big open laboratories' (Batterbury, 2001) that provide the ideal conditions for testing a suite of techniques (conservation tillage, stone lines, earth bunds, dikes, half-moons, tied ridges, etc.), aimed at checking soil erosion, enhancing the capacity of soils to retain and store water and increasing food or fodder availability in the Sahel (Mando, 1997; Zougmoré et al., 2000; Zougmoré et al., 2003). Whereas these techniques can differ in their design, they are almost all established for the same purposes: (1) to concentrate rain water; (2) increase its infiltration and storage in the soil; and (3) allow good plant growth.

One popular technique among farmers in the Sahel is 'zaï'. The 'zaï' technology consists in several 20-to-80cm-diameter pits scattered over the hardened field and partly filled with organic residues at the end of the dry season. The premise is that during the rainy season, the pits trap rain water and the activities of termites facilitate water infiltration and the release of nutrients for millet or sorghum crops. This pit planting method is widely used in the Central Plateau of Burkina Faso, where bare and hardened soils, locally known as 'zipellé', are common. In Niger, two projects, the Projet Agro-Sylvo-Pastoral (PASP) funded by the German cooperation and the Projet Gestion des Resources Naturelles (PGRN), have been promoting 'zaï' farming. It is difficult to establish the actual area, but it is estimated that thousands of hectares of crusted, degraded land have been rehabilitated and brought back to agricultural production in the region (Fatondji, personal communication).

Half-moons have also been widely tested in the hardened soils of Burkina Faso, Mali and Niger, and stand as an effective tool to harvest runoff water and facilitate the establishment of crops or seedlings. In an experiment conducted by Zougmoré et al. (2003) in Burkina Faso, half-moon practice, associated with different amendment or fertilisation treatments, has enable the production of between 500 kg per hectare (half-moon + recommended mineral fertilizer) and 1600 kg per hectare (half-moon + animal manure) of sorghum grain (Table 5). The relatively low yield with the recommended mineral fertiliser was due to increased soil acidity in this treatment. Half-moon without fertiliser or amendment produced 41 kg ha^{-1} while sorghum in the control plot died because the soil was too hard for the roots to establish. This study also showed much greater soil water content in the rooting zone of the half-moon plots compared to the control. However, the low yield in the 'half-moon alone' treatment shows that beside water, low soil fertility and acidity are other edaphic constraints that need to be addressed.

Table 5. Effect of half-moon practice on sorghum performance in Pougyango village, Burkina Faso (modified from Zougmoré et al., 2003)

Treatment	Grain yield (kg ha-1)	
	1998	1999
Control (no digging, no amendment)	0	0
Half-moon without amendment	41	42
Half-moon + animal manure	1614	1104
Half-moon + compost	1000	875
Half-moon + compost + rock phosphate (BP)	927	1104
Half-moon + BP + NPK fertiliser + urea	500	521

Stone lines and grass strips have shown similar results, although grass strips have the disadvantage of needing time for regrowth after the long dry season and hence may not be effective during the first and incidentally the most erosive storms (Zougmoré et al., 2004). These technologies have proved to be very practical in erosion prone soils, and more so in erratic rainy seasons. However, their effects are enhanced with the use of organic amendments. It has been demonstrated that the establishment of stone lines in a degraded soil in Burkina Faso allows the maintenance of sorghum yield at a level twice as high as that of control plots (Zougmoré et al., 2004). Runoff control, water infiltration and sorghum yield increases with the number of stone lines on the plot.

A modelling exercise has been used to make the benefits of increasing rainfall infiltration more perceptible. For example, a whole-farm analysis carried out in Mali showed that increasing rainfall infiltration from its current 40 percent level to 60 percent (combined with small amounts of chemical fertilisers) could help farmers improve food grain production by 60 to 90 percent, depending on rainfall. This, in financial terms, would translate into a two-to-four-fold increase in disposable income. With 80 percent infiltration, income could even be increased another 50 percent (Day and Aillery, 1988). Hengsdijk and van Keulen (2002) also demonstrated that the use of tied ridges in the semi-arid zone of Mali could increase average millet yield by 40 to 230 percent depending on soil type while reducing inter-annual variability in yield. Other options such as supplemental irrigation using harvested rainwater in low-cost manually dug farm ponds have also been explored and have proved to be helpful in bridging dry spells. A study by Fox and Rockström (2003) showed the effect that 60 to 90 mm of supplemental irrigation applied at actual occurrence of dry spells had on sorghum yield. Supplemental irrigation alone (712 kg per hectare) and fertiliser alone (975 kg per hectare) significantly increased yields compared to the control plots, which received neither fertiliser nor irrigation (455 kg per hectare). When supplemental irrigation and fertiliser were combined, 1403 kg of sorghum was produced per hectare, i.e. more than three times what the control plot yielded

6.3.3.2. Why soil and water conservation strategies need to be supported in the context of climate change

Given the role of land degradation in the exacerbation of climatic problems, investing in soil and water conservation is an almost unavoidable step in the quest for solutions to climatic hazards and future climate change in the Sahel. Losses of agricultural soils and rain water needs to be checked to reduce agricultural drought, flooding and inter-annual variability in food production, which exacerbates vulnerability among rural communities. In the deep sandy soils where water loss is mostly by drainage, the use of conservation tillage, organic amendments, combined with low levels of fertilisers and dense planting, has proven to be effective in reducing agricultural drought with the improvement of the water use efficiency (WUE) of crops. Manure can be readily available in the Sahel given the abundance of livestock and the tendency of sedentary farmers to keep an increasing number of animals. Corralling animals directly in the fields can provide solution where the application of manure can be constrained by transport and labour. The use of other soil and water conservation techniques such as tied ridges and stone lines or vegetation lines should also be encouraged to improve water infiltration and storage in the soil.

One major advantage of pursuing soil and water conservation technologies is that they can constitute a launching point for agricultural intensification. One factor that discourages small holder growers in semi-arid areas to adopt improved technologies is moisture stress. Pit planting techniques significantly contribute to solving this problem since runoff water is gathered and directly made available to crops. Moreover, they can facilitate the use of supplemental irrigation. Given the acidity of these soils, the use of organic amendment (manure), supplemented with small doses of inorganic fertilisers, is the best option to improve food security and income, hence the adaptive capacities of farmers. In South Africa, the use of high yielding sorghum hybrids, combined with water retention technologies (weed control in the off season and cultivation) and moderate to high levels of fertilisation, give yields of up to 7 tonnes per hectare (Ahmed et al., 2000). Soil and water conservation can therefore be a powerful tool not only to restore degraded land and control desertification but also could contribute meaningfully to sustaining crop production and mitigating the negative effects of climate change.

A higher level of investment is needed, however, to rehabilitate the bare crusted soils, common in the Sahel. Tilling or pit planting techniques such as zaï or half-moons provide the best solutions and need to be pursued with great urgency. However, the labour-intensive nature of these soil and water conservation techniques constitutes a major constraint, which can discourage many farmers. Thus, the implementation of these techniques warrants a strong support from governmental institutions, NGOs and other agencies involved in rural development. Indeed, because of the strong environmental implications at the watershed and regional levels, the recovery of degraded land should be considered as top priority by the Sahelian governments. The work carried out in areas such as the Central Plateau of Burkina Faso should be scaled up to other areas of the Sahel having similar constraints with the help of NGO's such as OXFAM and GTZ, which have a solid experience on the ground. The labour force can be supplied by the local people in the form of in-kind contribution. Schemes such as 'food for work' or the distribution of agricultural inputs to farmers have also proven to be practical in mobilising local labour in some areas.

6.3.4. Agroforestry

Agroforestry has been practiced in Sahel since time immemorial, the traditional parkland system being a trademark practice throughout the region. However, agroforestry research in Africa gained momentum only recently with the foundation of the International Council for Research in Agroforestry (ICRAF), now the World Agroforestry Centre. The Semi-Arid Lowlands of West Africa (SALWA) programme, which covers Burkina Faso, Mali, Niger and Senegal, was initiated as a contribution of ICRAF to the implementation of the Desertification Convention in the Sahel region. Agroforestry contains many useful attributes in relation to the conservation of biological diversity and the improvement of system resilience against climate extremes, all of which may be of interest regarding adaptation to climate change. Agroforestry therefore constitutes the ideal land use system that establishes synergistic links between the three major environmental conventions, namely the UNCBD, the UNCCD and the UNFCCC.

6.3.4.1. How can agroforestry be relevant to climate change adaptation?

The effects of different agroforestry techniques in enhancing the resilience of agricultural systems against adverse impacts of rainfall variability, shifting weather patterns, reduced water availability, soil erosion as well as pests, diseases and weeds have been well documented. A successful and well-managed integration of trees on farms and in agricultural landscapes results in diversified and sustainable crop production, in addition to providing a wide range of environmental benefits. Some of the mechanisms through which agroforestry practices may improve the resilience of agroecosystems in the occurrence of extreme climate are improved microclimate and reduced evapotranspiration. In the African drylands, where climate variability is commonplace and adverse impacts of climate change are expected, farmers appreciate the role of trees in buffering against production risk (Ong and Leakey, 1999). The parkland farming system, a farming practice whereby a few selected useful trees are encouraged to grow in a scattered distribution on agricultural land, is one interesting example. One of the most valued (and probably most intriguing) trees in the Sahel is Faidherbia albida. Thanks to its reversed phenology (the tree sheds its leaves during the rainy season), F. albida significantly contributes to maintaining crop yield through biological nitrogen fixation (BNF) and favourable micro-climate while minimising tree–crop competition. A study on a Faidherbia albida – millet parkland system in Niger demonstrated that shade-induced reduction of soil temperatures, particularly at the time of crop establishment, is critical for good millet growth (Vandenbeldt and Williams, 1992). Furthermore, the protein-rich leaves, twigs and pods of Faidherbia albida constitute a precious source of animal feed for livestock during the long dry seasons in the Sahel.

Table 6. Mean temperature (T), duration when temperature exceeds 40°C (H40), photosynthetically active radiation (PAR) and millet biomass harvested under and away from the tree canopies (adapted from Jonsson et al., 1999)

Treatment	T (°C)	H40 (h week $^{-1}$)	Millet biomass (g dry weight plant $^{-1}$)
V. paradoxa (large)	–	–	46.2
V. paradoxa (small)	29.1	1	43.3
P. biglobosa (large)	28.3	9	56.2
P. biglobosa (small)	27.0	5	36.8
Control*	29.98	27	39.8

***Control plots away from tree canopies.**

This type of reversed phenology is not observed in other parkland trees such as the shea butter tree (Vitellaria paradoxa) and néré (Parkia biglobosa), which have a negative shading effect that may reduce millet yield under the tree by 50 to 80 percent in some cases (Kater et al., 1992). Farmers are well aware of this loss in yield, but do not mind it since the economic benefits from harvesting marketable tree products largely compensate for the loss of crop yield. However, in extremely hot conditions (which we may have to face in the future) the shading effect of these evergreen trees could well be needed to compensate for the yield losses occasioned by the excess heat in the open areas of the field. Such a hypothesis has been validated by the work of Jonsson et al. (1999), who measured variables including temperature and millet biomass under and away from tree canopies in a parkland system (Table 6). The results indicate that despite the heavy shading, similar amounts of millet biomass were obtained from under these trees and the open plots. This absence of yield penalty under trees was, to a great extent, explained by the fact that millet seedlings under tree canopies experienced only 1–9 hours of supra-optimal temperatures (higher than 40 degree C) per week compared with 27 hours per week in the open. In other words, the shorter exposure to extreme temperatures as a result of tree cover compensated for the millet biomass loss, which would otherwise have occurred as a result of shading. This underscores the important role trees could play in mitigating the negative effects of extreme temperatures on crops, especially in semi-arid regions such as the Sahel.

The benefits of live hedge technology are also being well appreciated by farmers in Mali and Burkina Faso. Since there are no rules regulating animal browsing during the dry season, live hedges are now emerging as an efficient method to fence off wandering animals, which are a major impediment to off season agricultural activities. The development of dry season gardening for fruits and vegetables provides many Sahelian farmers with a useful fallback to compensate for the loss of crop production due low rainfall and degraded soils. This is also a sub-sector many governments are supporting in their poverty reduction strategies to diversify crop production and increase exports. While the primary goal of fencing with trees is naturally to protect crops against animal encroachment (Bonkoungou et al., 2002), products such as fruits, fodder and firewood can also be of great contribution in improving nutrition, farmer income and easing pressure on natural resources. In addition, a fenced plot creates a sense of ownership and security and hence can encourage investment. In Senegal also, the establishment of filao (*Casuarina* spp.) bands in the Niayes (the coastal stretch north of Dakar) has brought life to places, where the progression of sand dunes and the marine winds (*embrunts*) had until recently rendered any type of agricultural activities impossible. Market gardening is now thriving in the area and provides a livelihood to an increasingly larger number of settlers.

Beside this biophysical resilience, which allows the various components of the agroforestry systems to withstand the shocks related to climate variability, the presence of trees in agricultural croplands can provide farmers with alternative or additional sources of income strengthening the socio-economic resilience of rural populations. Tree products (timber, fodder, resins and fruits) are normally of higher value compared to maize or hard grains such as millet and sorghum and can buffer against income risks in case of crop failure. Studies in the Sahel have shown that products from *Parkia biglobosa* can earn a family a yearly income of up to US$ 270, which in fact is double what crops normally produce. Other species such as *Vitellaria paradoxa*, *Adansonia digitata* (baobab) and *Tamarindus indica* (tamarind) are of similar importance (Bonkoungou et al., 2002).

One of the legacies of climate variability in the Sahel, and which is likely to be aggravated by climate change, has been the acute shortage of dry season fodder. This situation is not just the result of poorly stocked pastures but can also be linked to the fact that some useful trees and shrubs, which once produced dry season fodder, are rapidly disappearing due to combination of factors including the recent drought conditions, the expansion of agriculture and the unchecked exploitation of forest products. ICRAF-SALWA and its various collaborators have been trying to find solutions to this problem by exploring ways of planting indigenous fodder trees in agricultural lands. Following a series of experiments both on station and in farmers' conditions in the four countries covered by the Sahel agroforestry network (Burkina Faso, Mali, Niger and Senegal), a list of promising tree and herbaceous species susceptible to be used as fodder banks has been elaborated, taking into account soil conditions and rainfall (see Bonkoungou et al., 2002). Over the last few years, a great amount of research has been particularly devoted to *Pterocarpus erinaceus*, a highly appreciated fodder tree growing naturally in Mali. The lucrative market that exists around this species in the vicinity of Bamako has inspired ICRAF and its partners to launch a special program on this tree. Preliminary results showed that *P. erinaceus* can be densely cultivated and yield enough leaf biomass to solve fodder problems during the dry periods in this part of the Sahel. From a financial standpoint, it is estimated that one hectare of densely planted *P. erinaceus* can earn its producer US$ 630 annually on fodder alone. This is a significant contribution in a country where yearly income averages US$ 27,

Table 7. Value of SEF products from SEF - ICRISAT Sadore station, Niger, during 2002 (adapted from Pasternak et al., 2005)

Species	Quantity-area	Yield/units	Unit Value (US $)	Revenue (US $)
Acacia colei[1]	320 trees/ha	2 kg seeds/tree	0.14	90
Zizyphus mauritiana[2]	63 trees/ha	30 kg fresh fruit/tree	0.12	225
Andropogon gayanus[3]	567 meters/ha	1 bundle/10m	0.8	45
Millet	1/3 ha	500 kg	0.1	50
Cowpea	1/3 ha	420 kg	0.2	84
Roselle[4]	1/3 ha	133 kg	0.8	106
Total	1 ha			600

[1] **Acacia colei seeds can be used in chicken feed**
[2] **Zizyphus mauritiana produces nutritious fruits that are consumed/sold fresh or baked into cakes**
[3] *Andropogon gayanus* **is a perennial grass that produces fodder especially in the dry season**
[4] **Roselle leaves are eaten as fresh legumes and the vitamin C-rich flowers are used to make juices and syrups**

Recently, researchers for ICRISAT developed an interesting model farm for the Sahel: the Sahelian Eco-Farm (SEF). The SEF concept provides an eloquent example of how an agroforestry-based integrated natural resource management regime can help improve the livelihood of the rural poor in climatically vulnerable regions such as the Sahel (Pasternak et al., 2005). The SEF is an integrated land use system that incorporates high value multipurpose trees/shrubs with soil and water conservation structures. The first on-station test was carried out at the ICRISAT Sahelian Centre in Niger in 2002. The premise was to provide a wide range of products and services: food, firewood, biomass for mulch and forage, cash, plant nutrients, increased infiltration of rainfall, improved soil organic matter, and protection from water and wind erosion. The economics of the SEF makes it a very attractive system; income from a one-hectare farm is estimated at US$ 600, a figure that represents 12 times the value of a typical millet crop (Table 7), whereas the establishment costs are relatively low: about US$ 60 per ha for the plant material and US$ 10 for the one time application of fertilizer. Labor for land preparation and tree planting was not considered since it is normally provided by the farming household. The SEF concept appears to provide a model for Sahelian farming households to break the endemic cycle of poverty and environmental degradation. The strength of the Sahel Eco-Farm lies in the fact that it promotes crop diversification and system resilience by combining various species of trees or shrubs (*Acacia colei* and *Zizyphus mauritiana*), grass (*Andropogon gayanus*) and annual crops such as roselle (*Hibiscus sabdariffa*), a relatively high value crop with food crops (millet and cowpea).

6.3.4.2. Conditions for agroforestry adoption in the Sahel

According to recent projections, the area of the world under agroforestry will increase substantially in the near future, especially in the tropics. Semi-arid areas should not be an exception to that. In the Sahel, agroforestry techniques such as windbreaks, live fences, fodder banks and improved fallows have been tried on an experimental basis, in addition to the indigenous parkland system. Establishment costs, labour and availability of seeds are three elements that have a strong influence on the adoption rate of agroforestry technologies. Since some of these agroforestry technologies are new to the farmers, training will be needed on areas such as nursery establishment, planting methods (timing, tree spacing, management, etc.).

Many agroforestry trees establish well when seedlings are used because they can withstand the biotic and abiotic pressure better than directly seeded plants in the initial stages. As shown in Zambia (Scherr and

Franzel, 2002), seedling production can be assured with the establishment of small-scale village nurseries, which are easier to manage than centralised nurseries. Furthermore, they require less labour and can reduce transportation costs and damage related to handling. In the Sahel, village nurseries make more sense than individual nurseries because of water constraints. Given the short growing season, seedlings need to be prepared during the dry period of the year to have any chance of being planted at the beginning of the rains and this can only be done where wells or boreholes exist.

Establishing agroforestry systems requires labour to be split between trees and agricultural crops, and managing these two components can be an overwhelming task to many households. But even when labour is available, planting and tendering trees, the benefits of which are not readily seen, may not be that appealing to some farmers, who would rather use that extra labour for other activities. We learnt from Warren's work in the Fandou Béri area of Niger that the households who enjoyed abundant labour or had better access to land often had the more degraded fields because they tend to expand their cultivation areas or resort to alternative income generating activities rather than investing in soil conservation (Warren, 2002). A study on the adoption of live hedges in Burkina Faso also led to a similar conclusion since farming households with a lot of labour can afford to install dead fences, which are much more labour demanding (Ayuk, 1997).

It is generally believed that farmers will be more inclined to adopt agroforestry technologies if these can produce immediate benefits. Therefore, even the agroforestry techniques are designed to serve long-term environmental purposes may need to include short-term benefits to stand a chance of being adopted at a large scale. Also, understanding the specificity of the Sahelian socio-economics is crucial in diffusing agroforestry technologies. In the Koutiala region of Mali, improved fallow can have such short-term effect as maize yield improvement (Kaya et al., 2000). Yet, it has been shown, based on modelling, that this additional grain production is not in itself sufficient as an incentive for farmers to plant tree fallows. Apparently, the technology is much more likely to be adopted if the trees used for fallow can produce fodder. In the Sahel, the importance of livestock is such that leaving densely planted trees on fallow fields un-harvested for a few years may be viewed as wasteful since the land could have served as grazing land. While improved fallow can work in this region, it will apparently need a particular 'Sahelian adaptation'. Leaving trees un-harvested during the fallow period, as is practised in Eastern and Southern Africa, is not an option here. Since fodder shortages are extremely frequent during the long dry seasons, harvesting tree leaves and using them as a supplement for fattening livestock or for sale in local fodder markets would be a much more sensible enterprise. This argument is all the more valid that some farmers in Koutiala do not even grow crops after cutting the trees. Nevertheless, the objective of improving the soil physical and chemical properties is still achieved through the abundant root biomass and the litterfall. In case farmers need to grow crops, it is advisable that the leaf biomass of the third (and last) fallowing year be incorporated to the soil before planting.

Seed availability is the next barrier to overcome in the promotion of agroforestry. The main reason why tree seeds are problematic is that, without any insurance, neither the private sector nor individual producers are ready to invest in such a highly uncertain domain. Trees may take years before producing seeds and this can have two major consequences. Firstly, the delay in investment return may be a deterrent to many who would consider venturing into tree seed production. Secondly, adoption of successful agroforestry technologies can be stalled because seeds are not immediately available to meet the demand. To surmount these barriers, ICRAF researchers, based on experience in Kenya and Zambia, propose the 'establishment of high-quality, high-productivity seed orchards for all candidate trees in the early stages of the technology development process so that sufficient seed is available for large scale adoption by the end of the trial period' (Simons, 1996; Scherr and Franzel, 2002). Of course this strategy involves a conscious wastage of seeds from all the tree species which will not have qualified for the technology. But a trade-off analysis showed that years of foregone benefits due to unavailability of germplasm are much more costly than having to waste unwanted seeds (Scherr and Franzel, 2002). In western Kenya, ICRAF has been involving individual farmers and farmer groups in tree seed production by volunteering germplasm and information to them and agreeing to purchase seed in the first years of production (Scherr and Franzel, 2002). The new seeds are than distributed to other farmers to diffuse the technology in other areas. The same methods could be extended to the

Sahel. However, it appears that a healthy collaboration between international research organisations such as ICRAF, governmental agencies and NGOs will be necessary to satisfy the increasing seed demand, which is likely to originate from a wide scale adoption of agroforestry.

7. Recommendations to make agriculture less vulnerable to climate change

To develop a resilient agriculture requires more important investments by governments and international agencies. There is widespread consensus that at least 10 percent of national budget need to be dedicated to agriculture within the next 5 years in order to significantly address problems related to food insecurity and poverty in Africa. In the framework of the New Partnership for African Development (NEPAD) process, African heads of state and government committed to that as expressed in the Maputo Declaration of 2003. These commitments are yet to be translated into practice, however. There is still an immense gap to bridge between the generation of agricultural scientific knowledge and its application to produce the expected benefits for the local people to whom it is targeted. Reasons why many useful technology options are under-utilised include high input prices and low output prices resulting from under-investments in markets and infrastructure, structural adjustment programs and distortions in international markets (IAC, 2004). This section gives a list of recommendations which, we believe, can make agriculture in the Sahel region more productive and more resilient to the various shocks that are going to occur in the future, including climate change. This list is not exhaustive nor are the recommendations given in any order of importance.

7.1. Foster the use of climate information to inform decision making

Inter-annual variability of rainfall is a major constraint to agricultural sustainability in the Sahel. Since climate change will exacerbate this problem, using seasonal climate forecasts to inform farmers, herders and other users will be necessary to avoid surprises, allow good use of favourable conditions and make the right decisions in case of an impending drought. The collaboration with regional and international climate research centres needs to be reinforced to acquire timely weather information.

7.2. Promote improved agricultural technologies

There is a strong need to accelerate the adoption of new technologies and varieties and more so that we understand that climate change is going to add new constraints to agricultural production. These include the use of drought-tolerant and drought escaping crops/varieties in areas where water deficits will be more pronounced due low rainfall or high evapotranspiration. Crop diversification is necessary and should be based on the potential of the different agro-ecological zones. Where water retention and supplemental irrigation are possible, agricultural production can be boosted in a significant way through the use of high-yielding varieties together with organic and inorganic sources of fertilisation.

7.3. Invest in soil and water conservation

Soil and water management strategies are necessary for two reasons. First, they are useful for sustainable crop production. Second, the techniques used have a great potential in buffering against drought and floods, which are likely to be more frequent with climate change. The degraded soils of the Sahel such as the "zipelle" of Central Burkina Faso need to be restored to allow crop production, control desertification and restore biodiversity. Simple techniques such as zai, half moon or mund bunds have proved to be efficient to concentrate water and increase yields especially in drought conditions.

7.4. Develop small scale irrigation schemes

There is an urgent need to increase the area under irrigation in the Sahel. Focus should be on areas where surface water is available. The boring of wells also can contribute to the development of horticulture. However, bearing in mind that global warming could exacerbate the scarcity of water resources through reduced rainfall/runoff and higher evaporation regime, technologies such as micro-irrigation that allow the economical use of water should be considered.

7.5. Invest in pest and disease control

Pests and diseases constitute a major threat to food security in the Sahel and climate change may aggravate the situation. For example, many observers linked the early invasion of the Sahel by the desert locust in the summer 2004 to climate change. However, no single country can address the locust problem on its own given its scope and ecology. A concerted effort, bringing together all Sahelian and North African (Algeria and Morocco) countries, supported by the United Nations agencies such as FAO and donor countries, will be needed to eradicate the problem.

7.6. Develop low cost post-harvest technologies

Damage of grain stocks by insect and other storage pests is responsible for a significant share of production losses. The African small scale farmers are permanently haunted by the fear of losing their harvests to storage pests, which forces them to quickly sell their grains when the price is lowest. Paradoxically though, they will have to purchase those same grains at very high prices later in the year. A warmer climate is likely to increase this pressure since the reproductive cycle of these insects might be shortened. One way of getting peasant farmers out of this trap, and hence reducing their vulnerability, is to reinforce their ability to store food using cheap conservation technologies. Techniques such as drum storage, solar disinfection, bagging technology and improved ash storage have real potential (Murdock et al., 2003).

7.7. Promote agroforestry

Agroforestry research and development needs to be strengthened given the various roles it can play in mitigating the negative effects of climate change. Policies should be put in place to rehabilitate degraded parkland systems and to accelerate the adoption of new technologies that can make a difference, preferably based on indigenous trees and shrubs. Promising technologies include the intensive planting of fodder trees such as *Pterocarpus erinaceus*, live hedges to support the development of off-season market gardening, windbreaks for wind-induced soil erosion control, and improved fallow to enhance soil fertility and reduce soil losses. The Sahel Eco-Farm is a good model of agroforestry system that could be scaled up in the region. The role of trees in improving microclimate, reducing soil erosion and generating income will be more important in the advent of climate change.

7.8. Develop processing industries

The development of agro-processing industries is a necessary step in the quest for food security in Africa, the Sahel in particular. These are necessary not just because they bring value addition to coarse grains but also because they can relieve rural women from drudgery and allow them to participate more effectively in income generating activities. The primary objective is to improve the nutritional conditions of the hunger-prone populations of the Sahel. But, given the importance of livestock and the severe fodder shortages in the dry season, the use of millet or sorghum as animal feed will have to be explored.

7.9. Modernise the livestock sub-sector

In the Sahel, some 60% of farmers' income is derived from animals, not from crops. Stocking is often considered as the first step in the process of diversifying from agriculture and constitutes a kind of insurance against crop failure. However, fodder and water scarcity during the dry season (between the months of February and June) is a major constraint for the development of this sub-sector. Estimates in Senegal put the loss in milk products due to seasonal hungers of livestock at a staggering 20 billion CFA Francs (40 million US dollar, 2004 value) (see Le Quotidien, 2004). There is, therefore, a great urgency in devising production systems that will improve animal nutrition. As discussed earlier, farmers appreciate the value of agroforestry technologies such as fodder banks and improved fallow, which can produce feed for animals in dry seasons. These technologies and others such as fodder millet, sorghum and cowpeas, should be encouraged. The use of animal feed from locally grown grains can also be of tremendous help. Local bovine races, although adapted to the tough Sahelian conditions, may not have the potential to fulfil the needs in meat and milk product for a better food security in the region. The improvement of these local races trough crossing with better performing races can make a significant inroad in improving food security and income. The artificial insemination technique has been introduced recently in the region and has shown great potential in addressing this issue. These actions should be complemented with increased investments in animal health.

7.10. Foster institutional linkages for agricultural sustainability

Diffusion of technologies to reduce vulnerability needs the participation of a wide range of stakeholders, partners and institutions. Since climate change may exacerbate rainfall variability, a close collaboration between meteorological and agricultural services will be necessary for a more effective use of climate forecasts. Extension services need to be strengthened and agents provided with the necessary equipments and logistics so that they can reach farmers more easily. Experience, in the Sahel and other parts of Africa, has shown the important role of NGOs in rural development. Thus, a healthy collaboration between extension services, NGOs and community-based organisations such as youth associations, women's groups may be more fruitful. To avoid intergenerational conflicts, religious and customary chiefs should also be consulted right from the beginning of the process. On-farm research directly involving farmers should be encouraged as much as possible since it creates a sense of ownership, facilitates technology uptake and save time and resources. Policies should also be put in place to encourage the contribution of the private sector for example through the signing of contracts with research organisations.

7.11. Develop special rural micro-credit schemes for small-scale farmers

Because of the lack of adequate rural financial facilities, smallholder farmers have often been by-passed by new technologies. The agricultural banks that exist usually target big commercial farms. Micro-credit schemes such the Rural Finance and Community Initiatives Project in Gambia should be revisited. Niger has also developed a credit program to finance income generating activities. The main targets of this program are Economic Interest Groups (EIGs) and rural women's groups.

7.12. Improve information delivery

Information delivery is critical in the process of enhancing the adaptive capacities of the rural areas to climate change. Information on weather or new technologies can be transmitted to the farmers using rural radios and other media such as mosques (for Muslims) and other gatherings such as traditional beer drinking ceremonies. The rapid development of mobile telephony is now opening up new opportunities and should be exploited fully to reach the otherwise remote and unreachable areas. Encouraging farmers' field days has also proven effective for the rapid spread of new technologies.

7.13. Invest in rural infrastructure

A positive correlation has been found between remoteness (expressed by the distance from roads) and the incidence of poverty, hence vulnerability to future climate change (Stifel et al., 2003). As in many African countries, the vast majority of the Sahelian population has only limited access to input and output markets because of defective road and information systems. Climate change can isolate Sahelian farmers even further since extreme climatic events such as floods can damage rural infrastructures and make roads impracticable. Without adequate investments in rural infrastructures, adaptation efforts through agricultural development will be a futile exercise. In the context of rural development, low-grade feeder roads have been shown to have more rapid impacts than high-grade roads as they allow better access to inputs and output markets (Table 8).

Table 8. Returns to government investments in rural Uganda (Fan et al., 2003)

Investment	Benefit/cost ratio	Reduction in numbers of poor per million Ush
Agricultural research and extension	22.7	107.2
Education	2.7	12.8
Feeder roads	20.9	83.9
Murram roads	n.s.	40.0
Tarmac roads	n.s.	41.4
Health	0.6	2.6

n.s. denotes effects were not statistically significant

Investment in health is necessary to eradicate infectious diseases such as malaria and water-borne diseases. The promotion of the 'cases de santé' has been a successful experience and should be extended with better equipment and more qualified medical personnel to improve sanitary conditions in rural areas. The HIV/AIDS pandemic is also becoming a major threat to rural development and a strong effort should be made to quell the problem. Access to clean water and education are also paramount and investments should be done in those areas.

7.14. Improve links to local, national and regional markets

Africa has one of the fastest urbanisation rates in the world and one consequence of that is the increasing demand in beef, milk, poultry products and fresh vegetables. Surveys have shown the existence of a healthy beef market not only in the urban centres within the Sahel but even more so in neighbouring coastal countries. Political integration is relatively advanced in West Africa with the existence of entities such as the Economic Community of West African States (ECOWAS), the West African Economic and Monetary Union (WAEMU) and this should facilitate market integration. To make this happen requires the development and/or reinforcement of mobility within the region. The major railway lines linking the major ports of the west African coast and the continental countries of the Sahel should be revamped, together with improved road networks.

7.15. Tap the opportunities offered by the Climate Convention

There is now a strong commitment from the international community to tackle the issue of climate change. The various funding sources that exist should be tapped to carry out vulnerability and adaptation studies and develop priority projects for funding in the agricultural sector. The NAPA process constitutes an important framework for the Sahelian countries. The adaptation funds, which are going to be available through the UNFCCC, the Kyoto protocol and other bilateral sources should be utilised in a more effective way to strengthen agriculture in the Sahelian countries.

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