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Agroecological innovations in a context of climate change in Africa

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Liste des abréviations

ACF	Action Contre la Faim (Action Against Hunger)
ACP	African, Caribbean and Pacific countries
AMCEN	African Ministerial Conference on the ENvironment
ARFA	Association pour la Recherche et la Formation en Agroécologie, (Association for research and training in agroecology)
AVSF	Agronomes et Vétérinaires Sans Frontières (Agronoms and Veterinaries without borders)
CARE	International solidarity NGO
CARI	Centre d'Actions et de Réalisations Internationales (Center for international actions and realizations)
CCD	Commission Climat et Développement (Climate and development commission of Coordination Sud)
CCFD	Comité Catholique contre la Faim et pour le Développement (Catholic Commitee against hunger and for development)
CFSI	Comité Français de Solidarité Internationale (French committee for international solidarity)
UNCCD	United Nations Convention to Combat Desertification
COP	Conference Of the Parties
CSFD	Comité Scientifique Français de lutte contre la Désertification (French scientific commitee to combat desertification)
CUMA	Cooperatives for the use of agricultural equipment
FTS	Fertilizer Tree Species
GRET	Groupe de recherches et d'échanges technologiques (Group for technological research and exchange)
GTD	Groupe de travail désertification (French working group on desertification, composed of NGOs)
IPCC	Intergovernmental panel on climate change
IRAM	Institut de recherches et d'applications des méthodes de développement (Institute for research and applications of development methods)
IRD	Institut de recherche pour le développement (French Research Institute for Development)
PNUD	Programme des nations unies pour le développement (United Nations program for development)
PROMMATA	Promotion d'un machinisme moderne agricole à traction animale - (Association for promotion of agricultural machinery based on animal power)
RAC	Réseau d'action climat (climate action network)
RADDO	Réseau associatif de développement durable des oasis (associative network for sustainable development of oases)
RéSaD	Réseau Sahel Désertification
RHK	Réseau des Horticulteurs de Kayes, Mali (Network of horticulturists of Kayes)
SRI	System of Rice Intensification
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
URD	Groupe Urgence Réhabilition Développement (group for urgency, rehabilitation and development)

Tables and figures

Introduction

Mean temperature and rainfall variability are expected to increase in many regions of the world according to climate change scenarios. These evolutions are often combined with more frequent extreme climatic events. Such changes have and will have negative effects on agriculture and food security. Indeed, cultivation season irregularity, heat waves or water scarcity largely disturb plants growth cycles and livestock production, limiting the availability of foods for human populations. This evolution of the climate is significantly accelerated by greenhouse gas emissions resulting from human activities. Climate change should therefore be mitigated by a reduction of these emissions and an enhancement of these gases. However, even if mitigation was addressed, which does not appear as a priority for most countries for now, climate change would still have widespread effects on agricultural activities. Thus, in order to maintain and improve food security, strategies of adaptation need to be elaborated. African populations are amongst the most vulnerable to climate change, because of their geographic and economic situations. In some parts of the continent where present climate variability already threatens food production; climate change could totally inhibit agricultural activities if no measures are taken to adapt existing farming systems to the new contexts. Peasants, who represent 70 to 80% of farmers in Africa, are likely to be the most vulnerable to climate change. There is therefore an urgent need to find solutions for maintaining agricultural production throughout the continent and improve working conditions. Peasants have developed farming systems that constantly respond to climate variability. The agroecological practices they implement represent a major potential to face the challenges of natural resources sustainable management and population growth. Local and international NGOs that work for the maintenance and development of peasant agriculture in Africa and elsewhere need to take into consideration these traditional and emerging techniques. Innovations have a greater chance to be accepted and appropriated if they come from the people who actually need them. There is therefore a need to take an inventory and study the relevance of practices of peasants in various contexts for adaptation to climate change.

Some papers focus on adaptation to climate change, while others emphasize the potential of agroecology for sustainable agricultural production. However, the link between those two themes has not been investigated in deep so far. This study aims at linking climate change, adaptation and agroecology and therefore intends to answer the following questions:

- Which climate changes have been observed and are projected in different climatic zones of Africa?
- How are such evolutions already influencing and expected to affect farming systems all over Africa?
- How do agroecological practices implemented by peasants contribute to their adaptation to climate change?
- To which extent is agroecology relevant to face the challenges of climate change and food security?

The study is geographically limited to four main climatic zones of Africa: arid, sub-arid, sub humid and humid tropical. First, the main trends of climate change and their concrete effects on farming systems in each of the four zones of study are identified. Then, the second part characterizes a referent farming system for each of the four zones before presenting the agroecological practices that have been inventoried in those systems as adaptation to climate change. The third part gathers examples of combinations of agroecological practices that allow farmers to increase the resilience of their farming systems to climate change effects. Finally, in the last part of the study, the potential of such practices for adaptation to climate change is discussed, to conclude on the relevance of agroecology to face climate change.

Methodology

How was the study carried out?

Characterization of climate change major trends

First, a literature review (scientific publications including IPCC reports, papers provided by the various partner NGOs) was carried out to characterize climate change observed and projected trends in the four zones of study, and impacts on African agriculture. In addition, discussions with two researchers of IRD permitted to validate this information. The results of this characterization were reviewed by several persons including NGO workers, IRD researchers and agroecology professors.

Identification and presentation of relevant farming systems to study

In the second part, relevant farming have been identified and characterized. One referent system was chosen for each of the four zones, according to two criteria: its representativeness of farming systems in the area, and its reliance on agroecological principles. The choice of these systems was discussed with the different NGO partners[1] working in Africa, to finally be validated. Then, review of literature and discussions with experts permitted to characterize those referent systems.

Inventory of agroecological practices in the referent systems

Interviews were led with 16 experts from 11 French NGOs which lead projects in Africa in agroecology. At least one NGO working in each of the four climatic regions was interviewed, in order to get information for the four zones of study (for detailed information on interview topics see questionnaire in Appendix 2). Interviews were led either face to face, by telephone or by skype. The notes taken were then transposed to finally be organized in "reading tables" that gather the major elements.
From the "reading tables" and information provided by literature, an Excel table was filled, inventorying all the agroecological practices mentioned. These results were sorted out according to the zone of study where they are implemented and presented in summarizing tables (see Appendix 4 to 7). Specific information on the different referent systems was then organized in graphics and mind maps for analysis (in Part 2).

Evolution of the methodology

Initially, there was to present one detailed agroecological innovation at each scale (plot, farm, territory) for each of the referent system. Through the discussions with partners, it appeared more relevant to follow a more systemic approach. Instead of one practice per scale, examples of combinations of agroecological practices implemented by farmers that contribute to enhance the system's resilience to climate change are thus presented. New interviews were therefore led with 6 experts of local NGOs from different African countries to get this information (see Questionnaire in Appendix 3).

The methodology of the study is summarized in **Figure 1**:

1 See list of people interviewed in Appendice 9

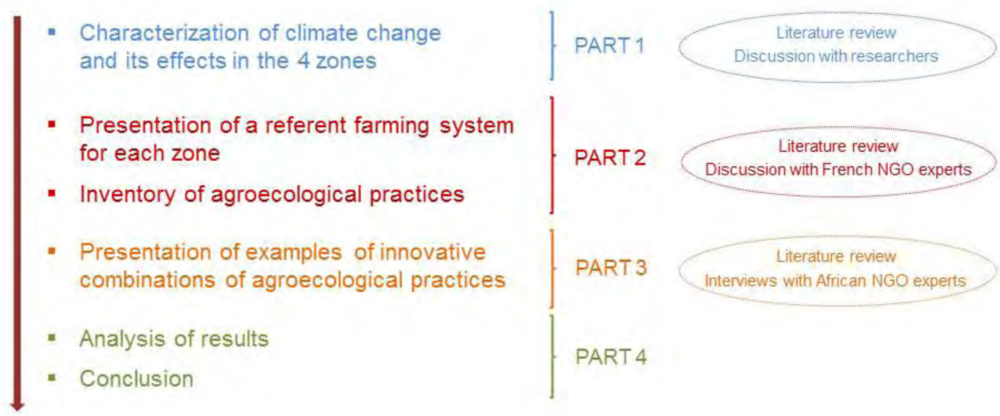


Figure 1 - Scheme of the methodology

Limits of the study

This study is far from exhaustive and cannot pretend to give a complete picture of all agroecological practices of African peasants. Mostly French NGOs' experts acting in different African regions have been interviewed. Although some local NGOs have also been questioned, the topic should be further studied directly with African peasants to get more insight. Furthermore, the focus on only some referent farming systems left aside other systems which may be also important. Also, available information was more restricted for humid zones, as interviewed people focus more on arid zones, where climate change effects are already more clearly identified.

Justification and characterization of the four zones of study

Why those 4 zones?

Climate change effects varying from one region to another one, its impacts need to be considered at a regional scale. The African continent was divided according to the Köppen-Geiger climate classification (presented in Appendix 1). The climate of the continent is controlled by complex maritime and terrestrial interactions that produce various climates from the humid tropics to the arid Sahara. Four zones were selected which are rather homogeneous in regards to climatic conditions. According to the map of Köppen-Geiger, the dominant climate in Africa is the arid B (57.2%) (in red and orange on the map), followed by the tropical A (31.0%) (in light and dark blue on the map) (Peel et al., 2007). We chose areas that are subject to either the global arid or the tropical climate, so that they are quite representative of the heterogeneity of Africa. Moreover, we chose to focus on areas where climate change is likely to seriously impact agricultural systems and local populations. Indeed, less brutal changes are predicted in equatorial and coastal areas (Christensen et al., 2007), which are not considered in this study (grey areas on the map).

1st	2nd	3rd	Description	
A			Tropical	
	f		- Rainforest	Zone 4
	m		- Monsoon	
	w		- Savannah	Zone 3
B			Arid	
	W		- Desert	Zone 1
	S		- Steppe	Zone 2
		h	- Hot	
		k	- Cold	
C			Temperate	
	s		- Dry Summer	
	w		- Dry Winter	
	f		- Without dry season	
		a	- Hot Summer	
		b	- Warm Summer	
		c	- Cold Summer	
D			Cold	
	s		- Dry Summer	
	w		- Dry Winter	
	f		- Without dry season	
		a	- Hot Summer	
		b	- Warm Summer	
		c	- Cold Summer	
		d	- Very Cold Winter	
E			Polar	
	T		- Tundra	
	F		- Frost	

Table 1 - Description of Köppen climate symbols (Source: Peel M. C., Finlayson B.L., MCMAGON T.A, Hydrology and Earth System Sciences Discussions Vol.11, n°5, 2007, p.1638. 2007)

Identification and presentation of the 4 zones

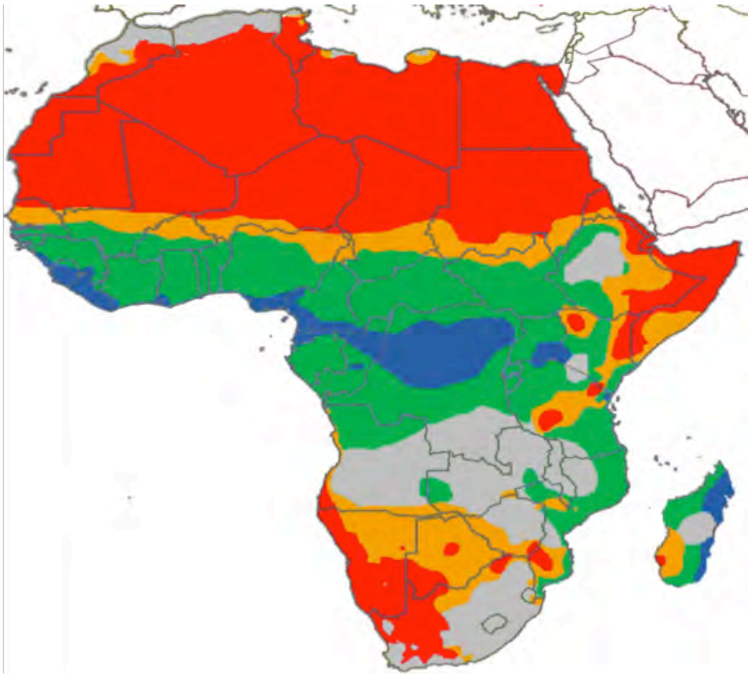
Table 1 briefly presents the different types of climates. Temperate and cold ones climate types were not selected as they are much less representative of African climates.
We will study the following climate zones, which are highlighted in **Table 1** and delimited in **Figure 2**:

Zone 1: Arid
(or dry tropical climate) which corresponds to the Desert (climate BWh and BWk).

Zone 2: Sub-arid
which corresponds to the Hot Steppe (climate BSh[2])

Zone 3: Sub humid
(or tropical wet-and-dry climate), which corresponds to the Savannah (climate Aw).

Zone 4: Humid tropical
which corresponds to the Rainforest (climate Af) and the Monsoon (climate Am).



Legend

Zone 1: Arid
Zone 2: Sub-arid
Zone 3: Sub humid
Zone 4: Humid tropical
Areas not considered in the study

Figure 2 - Delimitation of the 4 zones of study (adapted from: Peel M. C., Finlayson B.L., MCMAGON T.A, Hydrology and Earth System Sciences Discussions Vol.11, n°5, 2007, p.1638. 2007)

2 In the climate BS, we chose to study only BSh (hot steppe), and not BSk (cold steppe).

The Arid zone is characterized by a dry climate. "Arid" regions can be defined as regions with a structural precipitation deficit (World Bank, 2013). This type of climate implies little rainfall and/or concentrated rainfall in short periods between long rainless periods. This region globally receives less than 50 mm of rain per year, with a water deficit lasting at least 8 months. Precipitation is less than half of potential evapotranspiration. Also, there are wide differences in temperatures between day and night (up to 50°C difference). During the day, temperature average range from 20 to 25°C, and can go up to 49°C. Hot and dry deserts are warm throughout the fall and spring seasons and very hot during the summer. Winter usually has very little if any rainfall. Such areas host very rare vegetation: mainly shrubs and short woody trees, adapted to survive the climate (International Sustainability Council, 2013).

The Sub-arid zone borders desert areas, with climatic conditions similar to those found in the desert. It receives 250 to 500 mm of rain each year. The dry season lasts for the major part of the year, followed by a short wetter season. Sub-arid areas are also characterized by seasonal extremes: the warmest month averages more than 29°C and the coolest as low as 16°C. The vegetation is mainly composed of short grasses, providing grazing for animals.

The Sub humid zone can be found between the tropical rainforest and desert biome. The climate is characterized by two distinct seasons: the very long dry season (winter), followed by a very wet season (summer) which can last up to six months. Monsoon rains begin in May, with an average of 380 to 650 mm of water falling during this period. The distribution of the rain is unequal: it is more rainy towards the tropical forest zone and less towards sub-arid deserts zones. Such conditions of humidity and heat allow for dense herbaceous vegetation to grow, with some shrubs and isolated trees, offering grazing to animals.

The Humid tropical zone is characterized by the rainfall it receives all year round, with an average of 1250 to 6000 mm, occurring mostly during the summer. Precipitations are very variable from one month to another, with winter drought in some regions. In addition, some areas are subject to storms and tropical cyclones linked to high precipitation. Temperature ranges from 20 to 34°C, with warmer temperatures during summer and a colder winter season of 2 to 4 months. This climate favors dense vegetation (International Sustainability Council, 2013).

Part 1: Expected effects of climate change on agriculture in the four zones of study

1.1) Which major climate trends over Africa?

Some of the increasing energy accumulated in oceans is then distributed on Earth surface, leading to a global raise of temperatures over the globe. Scientists of the Intergovernmental Panel on Climate Change (IPCC) are modelling these climate changes to determine scenarios for the future. The most optimistic one, so called "low-emissions scenario", which considers a reduction of greenhouse gases emissions, expect global temperatures to increase by 1 to 2°C across Africa compared to mean temperatures of the 20th century, and to stabilize by 2100. A pessimistic high-emissions scenario predicts a 3.5 to 5°C increase in temperatures by 2100, with further warming in the following decades if emissions keep increasing (Masson-Delmotte, 2015). This warming is expected to be faster over Africa than over other areas. It should concern most of the African continent by the end of the 21st century, with greater changes over northern and southern arid regions and relatively smaller ones over central Africa (IPCC, 2014).

Higher temperatures affect rainfall patterns: volume and distribution of precipitations in space and time, often implying weather extremes. The main climate changes in Africa which are likely to affect agriculture concern temperatures and rainfall.

1.1.1 Observed and predicted evolutions of temperatures over Africa

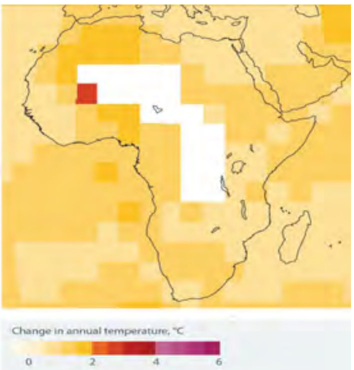


Figure 3 - Change in annual average temperature in Africa, 1901-2012
(Source : IPCC, Climate Change 2014 : Impacts, Adaptation and Vulnerability, 2014, pp.64-65)

As we can see in **Figure 3**, it is very likely that mean annual temperatures have increased in the past century over most of the African continent, with a faster increase for minimum temperatures than for maximum ones (IPCC, 2014). Between 1906 and 2006, Denhez (2007) estimates that average temperatures have globally increased by 1.4°C over Africa.

By 2050, average temperatures are predicted to rise by 1.5 to 3°C, and will continue further. Although there lacks historical data to determine trends in large areas of Africa (white areas on the map), average temperatures are likely (66% chance) to increase more in drier subtropical regions than in the moister tropics (IPCC, 2014).

In parallel of global warming, it is expected that unusual and unprecedented heat extremes will occur with higher frequency during summer months (World Bank, 2013).

1.1.2 Observed and predicted evolutions of rainfall patterns over Africa

Available data indicates that rainfall patterns are changing across Africa, as we can see in **Figure 4**. Rainfall trends vary greatly over time and location, and are therefore more difficult to assess than temperature evolutions. On the one hand, the amount of precipitations has decreased in some areas, mainly in western Africa and the north of Madagascar. There, an average annual decrease of about 25-50 mm has been observed between 1951 and 2010 (Christensen et al.,

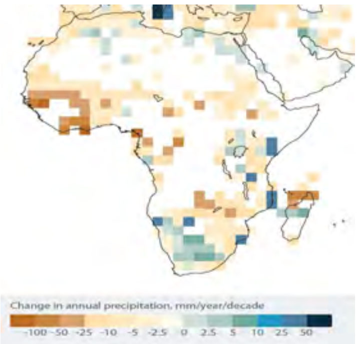


Figure 4 - Change in annual average rainfall in Africa, 1951-2012

(Source : IPCC, Climate Change 2013 : The Physical Science. Summary for Policymakers, 2014, p.8)

2007). On the other hand, average annual rainfall has generally increased each decade in areas of southern and eastern Africa in the same period (Christensen et al., 2007). However, rainfall trends in eastern Africa vary greatly over time and location. Also, most areas of Africa lack sufficient significant data (white areas on the map) to draw conclusions about trends in annual rainfall over the past century (IPCC, 2014). In addition, weather extremes have been observed. During the last 30-60 years, extreme precipitation events, such as droughts and heavy rains, have been experienced more frequently in eastern Africa (Christensen et al., 2007).

It is estimated that much of the subtropics will dry while there will be an increase, or little change, in precipitation in the tropics (Christensen et al., 2007). Arid regions are therefore expected to spread.

Furthermore, rainfall will very likely be more episodic and brutal on the whole continent (Denhez, 2007). Indeed, extreme climatic events are expected to become more frequent: more frequent droughts projected in central and southern Africa; and higher risk of flooding expected in the Horn of Africa and part of East Africa (World Bank, 2013).

Mean temperatures are globally rising over Africa, and expected to increase by up to 3°C by 2050. In addition, rainfall patterns are becoming increasingly unpredictable, with greater variability over time and space. Depending on the regions, extreme weather events such as heatwaves, droughts, heavy rains and floods are also expected to become more frequent and intense.

1.2) Which implications for agriculture in Africa?

The 5th Assessment Report of the IPCC (2014) provides many evidences of climate changes in recent decades which are already affecting natural and human systems on all continents. Even under most optimistic IPCC scenarios, climate change will have widespread impacts on food security, water availability, livelihoods and human health in Africa. Indeed, many Africans are economically dependent to primary sectors such as agriculture which is often considered as the human activity that is the most dependent to climate (Sultan, 2008). Yet, this activity employs almost 70% of the population in most African countries. The agricultural sector represents in average 21% of GDP in Africa, with a contribution ranging from 10 to 70% depending on the country (Boko et al., 2007). Expected changes in rainfall, temperature and extreme event frequency and intensity should have both direct and indirect impacts on aridity, crop yields and agro-pastoral and livestock systems (World Bank, 2013), as well as on socio-economic factors. Resources increasing scarcity accentuate the risks of conflicts.

The main staple foods in Africa are cassava, rice, soybean, wheat, maize, millet and sorghum (Adesina, 2010, cited in World Bank 2013). In Sub-Saharan Africa[3], 97% of total crop land is rain-fed and it is mainly located in sub-arid regions as tropical areas are unsuitable. Many African countries do not have efficient irrigation systems (Boko et al., 2007). The livestock sector is also very important in Africa, with a concentration in sub-arid and sub humid zones, because of susceptibility to diseases and low digestibility of grasses in tropical environments. Agricultural systems are therefore highly reliant on rainfall and thus vulnerable to changes in precipitation and droughts. Besides the challenges of climate change, African farmers also have to cope with constraints such as poor soil fertility, pests, crop and animal diseases and restricted access to inputs and improved seeds (Boko et al., 2007). Climate changes and hazards are aggravating the already challenging situation, threatening populations' livelihoods (World Bank, 2013).

3 Part of the African continent below the Sahara desert

1.2.1 Effects of temperatures evolutions on agriculture

Temperatures evolutions factors

Warming could contribute to the loss or degradation of arable land. A raise in average temperature stimulates the **respiration process.** Only in case of sufficient water availability, when temperature rises, photosynthesis also increases. This phenomenon implies a risk of carbon loss in the soils in dry areas when temperature rises (Ciais et al., 2013), which affects soil fertility. Also, Mueller et al. (2012, cited in World Bank 2013) emphasize that the yield potential of arable land is often higher than actually achieved, because of various factors including water availability. Those limiting factors could be reinforced by climate changes.

Warming could also directly impact crops as their growth strongly depends on environmental factors. Where there lack precipitations, when temperature rises, soils dry out and all heat results in **increased surface temperature** (World Bank, 2013) which can have different impacts on crops. First, it can promote **fungal growth** that kills seedlings in case of relative humidity. Secondly, the IPCC (2014) underlines that some of the major crops in Africa are highly sensitive to changes in temperature. Luo (2011, cited in World Bank 2013) explains that crops such as maize, wheat and sorghum have **high temperature sensitivity thresholds** and large yield reductions are observed once the threshold is exceeded. For instance, for each day in the growing season spent at a temperature above 30°C, maize yield reduces of 1% compared to optimal, drought-free rain fed conditions (World Bank, 2013). The photosynthesis rate, which is a key factor for growth and yield, of wheat and rice is at a maximum for temperatures of 20 to 32°C. Local warming may also provoke an increase of **potential evapotranspiration.** To grow under warmer conditions, standard crops would have to release more heat through evapotranspiration to survive. In sub humid and drier regions, moisture is the main factor constraining the growing season length. Warming would thus **shorten the growth season,** leading to **reduced crop yields** and **higher risk of crop failure** (World Bank, 2013). In addition, temperatures, water availability and CO_2 concentration may alter grasslands' quantity and quality by influencing their species composition. In areas receiving more rainfall there is enough water available for evaporative cooling though, limiting surface warming.

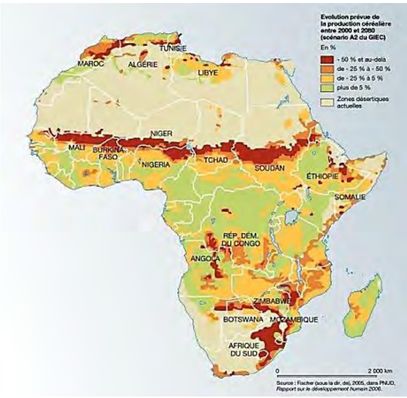


Figure 5 - Expected evolution of cereal production between 2000 and 2080

(PNUD, Rapport mondial sur le développement humain, 2005)

Consequences for agricultural production

A 2 to 3 °C increase of global mean temperatures should globally stimulate agricultural production on Earth; only its distribution will be more unequal. Global repartition of cereals producing regions will be modified by climate change, accentuating current inequalities. Warmer countries will have to face increasing losses of arable land and more restricted access to water resources, which are already accentuated by inappropriate management. By the 2080s, it is estimated that the proportion of arid and sub-arid lands in Africa will increase by 5 to 8% (IPCC, 2014).

The loss of arable land will certainly be accompanied by a decrease in crop yields. Even moderate increases, of 1 to 2°C, are likely to negatively affect yields of major cereals and further warming will have increasingly negative impacts (World Bank, 2013) although the degree of loss is variable depending on the region (IPCC, 2014). Figure 5 presents the expected evolution of cereal production between 2000 and 2080 in Africa. We can see that the sub-arid zones are likely to be the most seriously impacted, with a decrease of more than 50% of cereal production (red areas on the map) in the Sahel by 2080. On the contrary, cereal production should be relatively favored in humid tropical zones and some parts of sub humid regions (green areas on the map).

Furthermore, heat and droughts affect livestock. Regional climate change is considered as the largest threat to the economic viability of pastoral food systems. Extreme heat and water stress may alter animals' feed intake, growth, reproduction, maintenance and production; and increase their mortality. Animals may also be affected by increased prevalence of diseases favored by warmer conditions. In addition, grasslands alteration may affect nutrient availability for animals and thus alter production quantity and quality. Nevertheless, large farms could be more vulnerable to higher temperatures than small farms as they generally rely on breeds such as beef cattle that are less suited to extreme temperatures. Smallholders generally breed species such as goats which are tolerant to higher temperatures. Nevertheless, both types of farms are considered vulnerable to rainfall patterns evolutions (World Bank, 2013).

Temperature extremes factors and consequences

Besides global warming, extreme weather events will also alter agriculture in Africa although implications have not been clearly identified so far. Heatwaves, which are projected to affect increasing proportions of Africa, will have adverse consequences for food production systems (World Bank, 2013). Schellnhuber et al. (2013) stress their impact on the vegetative cover, and the threat of extinction they imply for various plant species. Moreover, Patz et al. (2008, cited in World Bank 2013) state that climate extremes can modify the ecology of plant pathogens, although very little research has been led on the effects of climate change on plant pests and diseases. The higher the levels of warming the stronger the negative impacts on food production (World Bank, 2013).

1.2.2 Effects of rainfall patterns evolutions on agriculture

Rainfall patterns evolutions factors

In regions where average rainfall is predicted to decrease, **water sources will become more and more restricted.** Soil quality is another major factor of the evolution of agriculture. In areas that will be subject to aridity, **the layer of fertile soil will become thinner.** Also rainfall patterns influence the **quality and quantity of plants in grasslands,** as they require water for their growth. If water lacks, only the most competitive plant species, which are not necessarily the most nutritive ones, will be able to survive. Moreover, rainfall increasing variability influences wet season's characteristics (onset and end dates, duration, and amount of rain).

Consequences for agricultural production

Precipitation regime's changes could indirectly affect farming systems. Rainfall patterns evolutions could exacerbate existing inequalities in water availability between the regions (World Bank, 2013) and accentuate the remoteness of production zones from aquifers will increase in Africa, especially in dry areas, limiting crop and animal production.

Rainfall evolutions could also have direct negative impacts on agricultural production. Indeed, increased aridity will affect crop yields, which are likely to decline as the growing season shortens (Denhez, 2007).

Furthermore, rainfall variability has direct and indirect implications for livestock production. Rainfall patterns influence several factors of livestock production including quantity and quality of feeds; and available grassland surface. Barbier et al. (2009, cited in World Bank 2013) observe that rainfall temporal distribution matters more for pastoral farmers than total amount of precipitation. Yet, increased rainfall presuppose a shift from grassland to forest; spreading of diseases vectors; and shift from livestock to crop production (Boko et al., 2007). Water stress may also directly weaken livestock, in particular because water consumption increases with warmer weather.

Rainfall extremes factors and consequences

The sustainability and quality of arable lands depend on the intensity and frequency of climate events such as droughts and heavy rains, as they generally damage the soil (Denhez, 2007). Moreover, plants putrefy because of heavy rainfall and are attacked by parasites favored by such climatic conditions.

In many parts of Africa climate change is not fully understood (Boko et al., 2007) and its local impacts cannot be simulated. Processes such as rainfall, evaporation and infiltration are not efficiently represented. Yet they are the phenomenon with the strongest ecological and societal impacts because they affect local climates at agricultural scale (Sultan, 2008). Furthermore, there exist some uncertainties about climate projections, the response of different crops to changing climatic conditions, and the coupling of climate and crop models based on different temporal and spatial scales. Climate models are generally consistent regarding the direction of warming in Africa whereas projections for precipitation are less certain (Boko et al., 2007).

Furthermore, although climate change is expected to affect mainly negatively agriculture in Africa, Müller et al. (2011, cited in World Bank 2013) suggest that it may have positive influence as well, depending on farm type and crop type and depending on whether or not adaptation is assumed. For instance, crops may respond positively to increasing atmospheric CO_2 concentrations by enhancing photosynthesis and water use efficiency and thus grain mass and number. But important crops such as maize, sorghum and millet are not very sensitive to atmospheric CO_2 concentrations, and the magnitude of these effects remains uncertain.

Vast proportions of African countries' populations rely on agricultural production (both crops and livestock) for livelihood and food security. This situation makes them critically vulnerable to climate change effects. Indeed, African peasants' rain-fed farming systems are particularly dependent to precipitation variability. Indeed, rainfall increasing variability is likely to further restrict access to water resources; shorten growth season; impact soil fertility; and alter quality and quality of available grass. These factors would lead to reductions of animals and crops productivity. In addition, warming further weakens agricultural production. It contributes to soil degradation and loss of arable land; crop yield and animal productivity reduction; alteration of vegetative covers; and pests and diseases spreading. Yields from rain-fed cultivation could decrease by up to 50% in some countries by 2020; and crop net revenues by 90% by 2100 (Somorin et al., 2010).

The relative significance of temperature and precipitation in the effects of climate change on agriculture vary depending on the regions. It is difficult to assess as they are closely linked and interact. Yield modification in arid zones may be mainly driven by rainfall changes, whereas it is more dependent to temperature in equatorial and temperate zones (World Bank, 2013).

Also extreme events could have significant consequences which are uncertain for now (Rötter et al, 2011, cited in World Bank 2013).

Climate change is therefore expected to affect agriculture by reducing the area suitable for cultivation and grazing; altering growth season length and yields potential; and limiting animal productivity.

Considering climate change implications, solutions have to be identified and implemented urgently in order to maintain and improve food security of African vulnerable populations and prevent conflicts spreading.

In the following section, the effects of climate change on agriculture in each of the four zones will be studied more in detail. These four zones of study present a high diversity of agricultural systems, depending on various factors including climate, environment and culture. This study focuses on rural agriculture rather than peri-urban production. Moreover, we will put an emphasis on peasants' strategies, as they represent the great majority of farmers in Africa.

1.3) Which challenges arising from climate change to agriculture in the four zones of study?

1.3.1 In the arid zone

Agriculture in arid Africa

Arid regions rely on the wet season for water and receive little runoff from permanent water sources. High temperatures and dry soils, which absorb more moisture, accentuate this phenomenon. Moreover, agricultural production in arid zones is subject to strong constraints such as low fertility of soils, due to low organic matter content, and high density of weeds

Figure 6 - Arid climate zone

and pests. Producers are mostly subsistence farmers, growing mainly cereals and legumes in rain-fed or specific irrigation systems. They also produce smaller amounts of roots, fibers, fruits and vegetables. Livestock production is limited by the scarcity of accessible grasslands (Wellington, 2007).

Climate changes in arid Africa

In the arid zone, climate is becoming drier and warmer in average during the year. Average annual rainfall is decreasing while mean temperature increases. In the worst case, local associations expect a 50% decrease of rainfall by 2060 in Morocco and Algeria (Cheneval and Michel-Queirel, 2012). Furthermore, extreme climatic events such as droughts, heatwaves and flooding should multiply (Kabat et al., 2002, cited in IPCC 2007). The number of heatwaves days per year is expected to increase over the 21st century (IPCC, 2014). In the Horn of Africa and in North East Africa, global climatic models predict an increase of rainfall whereas regional climatic models expect drier conditions. If rainfall was to increase, it would be during periods of heavier rainfall instead of being uniformly distributed during the year, accentuating flooding risk (Schellnhuber, 2013).

Effects on water resources

Water resources will be affected by these climate evolutions. Globally in this zone, arable land surface will decrease while arid and desert zones spread (Cheneval and Michel-Queirel., 2012). Drier conditions will accentuate water scarcity and further limit farmers' access to water whereas crops water requirement increase with higher temperatures. There will thus be a general increase in irrigation demand, whereas uncertainty about rainfall and rivers flow is increasing. Production zones are more and more isolated from aquifers, especially in Maghreb. In Egypt, about 85% of the annual total water resource is consumed by agriculture, which contributes to about 20% of GDP (Boko et al., 2007). In this country, more than 70% of the cultivated area depends on low-efficiency surface irrigation systems that lead to high water losses, lower land productivity, waterlogging and salinity problems. Unsustainable agricultural practices and water management impact water quality, which can in turn affect irrigated soils and crops.

Effects on soils and landscapes

Climate change is expected to exacerbate the effects of anthropic factors (deforestation, fires, erosion…etc.) on soil quality. Evapotranspiration, stimulated by high temperatures and limited rainfall, reduces water resources in the soil which dries out and becomes increasingly sensitive to erosion. In addition, increased frequency of extreme climatic events such as erratic rains after dry periods is likely to accelerate the erosion process. Higher evaporation also increases soil salinity, affecting their fertility. Higher temperatures may also be responsible for a loss of fertility in the soil as they stimulate the decomposition process, which can lead to losses in organic matter. Agriculture in the arid zone will therefore also be affected by heightened soil degradation.

Implications for agriculture

Local associations expect climate changes to negatively impact yields of staple foods by 2020. Irrigated crops will see their water requirements increase with temperature rise. Cereals have different capacities of adaptation, depending mainly on their resistance to higher temperatures and lower water availability. According to local associations, their global yields could be reduced by 5.7 to 14% in Algeria and by 10 to 50% in Morocco. In Egypt, rice, which type of photosynthesis cannot bear rapid and high increase of mean temperatures is likely to give lower yields, unless farmers adapt its culture and choose other varieties. Maize will also be impacted by the frequency of droughts. Wheat, which can grow in a large range of climate, should be less impacted, unless the mean temperature increases by more than 4°C (Denhez, 2007). Climate change will also negatively affect legume yields. Some local association experts estimate that small and average irrigated farms are likely to shift to rain fed systems as water availability declines. Furthermore, changes in climatic conditions may favor the emergence of pests and crop and livestock diseases that did not exist in arid areas.

Influence on food security

Climate change may exacerbate socio-economic issues. In the Maghreb, local associations predict that natural resources degradation and agricultural yields reduction are likely to provoke a great diminution of the cereal offer by 2050. Also higher temperatures will limit storage capacity. The IPCC (2007) estimate that, by 2100, parts of the Sahara are likely to be the most vulnerable, with agricultural losses of between 2 and 7% of GDP. Moreover, unstable prices of foods will make them less accessible for vulnerable populations. Climate changes are thus threatening food security in the arid zone. Furthermore, the drought in Somalia particularly exacerbated conflicts and insecurity. It led to the displacement of large numbers of Somalis inside the country or to Ethiopia and Kenya (USAID, 2012 and McMichael, 2012, cited in World Bank 2013).

Subsistence farming of African arid regions is threatened by the following major climate changes: increase of mean annual temperatures; reduction of annual average rainfall; higher spatial and temporal variability of rainfall; more frequent and longer droughts; more frequent and intense heat waves; and more frequent and intense floods. Such evolutions generate great challenges for farmers, which are summarized in Table 2.

Table 2 - Main challenges for farmers in the arid zone regarding climate changes

Affected factor	Impacts on natural resources and production means	Challenges for farmers
Landscape	Expansion of desert zones	Loss of arable land
Water	Lower quantity of available water Higher uncertainty about water availability in time and space Low-efficiency surface irrigation systems Increased crops and animals water requirements	Lack of water supply for crops and animals
Soil	Higher soil salinity Accentuated evapotranspiration Loss of organic matter	Reduction of soil fertility
Plants	Sensitivity of crops to heat Destruction by flooding and heat waves Pests and diseases spreading Limitation of crop storage capacity	Loss of crops Reduction of crop yields Reduction of products shelf life
Food security	Reduction of arable surfaces and crops yields Unstable prices of foods Accentuated conflicts and Insecurity	Reduction of cereal offer More uncertain access to foods Migrations of workers

1.3.2 In the sub-arid zone

Agriculture in sub-arid Africa

In sub-arid regions, steppes are often converted to cropland and pastures. Rain-fed cultivation is the main food resource and the main source of income, for a population that is growing increasingly quickly. Agricultural production is particularly dependent to the following factors of rainfall: onset date of rainy season, distribution of rainfall during rainy season and annual sum of rainfall. The types of crops cultivated are linked to average annual precipitations. In driest regions, we find mostly cereals and livestock, with transhumance systems. In some sub-arid regions, livestock systems are the main source of livelihoods. In Botswana for instance, more than 40% of the nation's resident rely on them. In more humid areas, cash crops such as cotton may be cultivated.

Climate changes in sub-arid Africa

An overall shift towards higher temperatures and lower annual rainfall has been observed in the sub-arid regions of Africa since the 1960s. Over West Africa and the Sahel, the number of cold days and cold nights has decreased whereas the number of warm days and warm nights has increased between 1961 and 2000. Also high warming rates are projected over the sub-arid parts of South Africa, Botswana and Namibia (IPCC, 2014). In the Sahel, average annual rainfall is estimated to have decreased by 20% since the 1960s (Sultan, 2008). This reduction has seriously impacted the main rivers flow and the filling of water storage for agriculture. Also, severe droughts of have affected the Sahel, the Horn of Africa and southern Africa in the 1960s (Christensen et al., 2007). Nevertheless, relative increase of rainfall has been observed in Central Sahel in the last decades, concentrated in short periods though (LOCEAN et al., 2015). Indeed, regional model studies suggest an increase in the number of extreme rainfall days over West Africa and the Sahel in May and July (IPCC, 2014).

Effects on water resources

Climate change will amplify existing water stress. The east-west band from Senegal to Sudan, separating the dry Sahara from wet Central Africa is identified as a critical "unstable" area regarding water availability (Boko et al., 2007). Climate changes will limit the access to irrigation water and reduce agricultural productivity, in particular for farmers and pastoralists with minimal capital. Also rainfall patterns increasing variability constitute a challenge for farmers who rely on the wet season for growing crops and for transhumance. Indeed, sowing at the very beginning of the monsoon leads to higher and more stable yields (Sultan, 2008). Farmers also have to consider the impacts that dry periods can have during the sensitive phases of plant development when settling their cropping calendar (Sultan, 2008). Rainfall increasing variability complicates cropping calendar planning.

Effects on soils and landscapes

Increased evaporation may provoke salinization and loss of organic matter, two phenomena that alter soil fertility. In addition, grasslands are sometimes overgrazed, when there are more animals than land can support, causing soil degradation (International Sustainability Council, 2013).

Implications for agriculture

Extreme climatic events cause damages to agricultural production. For instance, in the Sahel, recurrent droughts and floods in the 1990s and 2000s have often destroyed crops and compounded food security problems (IPCC, 2014). Floods combined with higher temperatures may favor the emergence of pests and crops and animals diseases that did not exist in those regions before. Moreover, Schellnhuber (2013) states that a 1.5°C warming by the 2030s could seriously limit the production capacity of sorghum in western Sahel and southern Africa. In addition, a 20% decline in tree density in the western Sahel has been observed since the 1950s, due to changes in temperature and rainfall variability (World Bank 2013).

In addition, climate changes imply some evolutions of farming systems. According to the World Bank (2013), mixed crop-livestock sub-arid systems in the Sahel and arid and sub-

Figure 7 - Sub-arid climate zone

arid rangeland in parts of eastern Africa are among the most vulnerable to changes in climatic conditions. In southern Africa, some farmers are switching from mixed crop-livestock systems to rangeland-based systems because of increased rainfall variability and shorter growing season. Areas may transition from rain fed mixed cropland to rangeland, with a loss of cropland surface. Such conversions also involve risks, including animal feed shortage in dry seasons (Thornton et al., 2009). Indeed, Djoudi et al. (2011, cited in World Bank 2013) emphasize the high dependence of dryland pastoral systems to natural resources such as pasture, fodder, forest products and water, which are affected by climatic variability.

Animals are thus also negatively affected by climate change in sub-arid regions. First, droughts can seriously impact herds, as it happened in 1984 in the interior delta of Niger River when more than 80% of the cattle were killed. Other example are the droughts that occurred between 1995 and 1997 in south Ethiopia, causing herders a loss of about 50% of their cattle and about 40% of their sheep and goats. Such evolutions may place livelihoods dependent on the sector at risk (Thornton et al. 2009, cited in World Bank 2013). Secondly, the surface of grasslands for livestock feeding is decreasing in some regions as the surface of flatlands inundated declines, limiting transhumance (Sultan, 2008). In Senegal, decreases in optimal stocking density have been observed, which can lead to lower incomes for affected farmers. Droughts in drylands also negatively impact vegetation diversity and productivity, limiting available fodder resources and grazing.

Influence on food security

Roncoli et al. (2001, cited in World Bank 2013) state that climatic risk and relative scarcity of natural resources lead to more precarious livelihoods in areas such as the Sahel where "people are living nearer the margins of subsistence". Also, the impacts of climate change on human activities can lead to serious social conflicts. Populations are forced to abandon activities that they had been doing for ages and this may provoke familial conflicts. In addition, competition for fertile land is getting stronger and creates territorial conflicts (Sultan 2008). Moreover, Faures and Santini (2008, cited in World Bank 2013) emphasize that relative poverty limits adaptive capacities of local populations, increasing their vulnerability, in particular in pastoral and agro-pastoral areas. These zones include parts of the Sahel region and of Angola, Namibia, Botswana, Zimbabwe, Zambia, Kenya, and Somalia.

Rain-fed cultivation and livestock breeding, which are the main source of foods and income of populations of sub-arid Africa, are threatened by the following major climate changes: increase of mean annual temperatures; higher spatial and temporal variability of rainfall; more frequent and longer droughts; more frequent temporary droughts; and more frequent and more intense floods. Such evolutions generate great challenges for farmers, which are summarized in Table 3.

Table 3 - Main challenges for farmers in the sub-arid zone regarding climate changes

Affected factor	Impacts on natural resources and production means	Challenges for farmers
Landscape	Shift from mixed crop-livestock to livestock-only systems	Reduction of arable land surface
Water	Lower quantity of available water Higher uncertainty about water availability in time and space	Lack of water supply for crops and animals More difficult planning of agricultural calendar
Soil	Higher soil salinity Accentuated evapotranspiration Loss of organic matter Overgrazing	Reduction of soil fertility
Plants	Sensitivity of crops to droughts and floods Destruction by floods Pests and diseases spreading	Reduction of crop yields Loss of crops
Animals	Reduction of vegetation diversity and productivity in grasslands Lower land carrying capacity Parasites and diseases spreading	Animal feed shortage Reduction of animal productivity Loss of animals
Food security	Abandonment of traditional activities Competition for fertile land Increasing scarcity of natural resources	Social conflicts Territorial conflicts More precarious livelihoods

1.3.3 In the sub humid zone

Agriculture in sub humid Africa

Conditions of heat and humidity in sub humid regions of Africa allow for very diverse crop and livestock productions. Savanna grasslands are generally grazed by cattle and goats. Peasant rain-fed agriculture is also part of the predominant livelihoods; mainly for subsistence although in some regions cash crops such as coffee or cotton are well represented. Farmers mainly grow maize, millet, sorghum, cassava, yam, groundnut, cowpeas and leguminous forage. Rain-fed mixed crop-livestock farming is also well represented (UNCCD, 2009).

Climate changes in sub humid Africa

Sub humid zones are subject to a high variability in temperature and precipitation, which could be accentuated by climate change. For instance, in Côte d'Ivoire, climate change is characterized by variations in the rainy season's onset and end dates. Annual amount of rainfall has decreased since the 1970s, with a general drop of 4.6% per year in the 1980s, and wet seasons have become shorter. Increased frequency of storms, heavy rains and floods has also been observed. Moreover, average daily maximum temperature for the warmest month of the year should increase by up to 2.5°C by 2050.

Effects on water resources

Rainfall increasing variability disturbs agricultural calendar, accentuating the risks for farmers and breeders. Also reduction of annual average rainfall is very likely to impact most farmers as their agricultural practices rely on the amount and seasonal distribution of rain (Comoé et al., 2013). Indeed, The UNCCD (2009) projects that soil moisture will reduce while heat stress increases.

Figure 8 - Sub humid climate zone

Effects on soils and landscapes

According to Schellnhuber et al. (2013), predicted evolutions of African ecosystems could lead to a reduction of savanna grasslands surface. By the time global warming reaches 3°C, savannas are expected to decrease from about a quarter at present. Moreover, increased concentrations of CO2 are likely to facilitate a shift from grassland to woodland savanna. Trees may outcompete shade intolerant grasses in savannas, intensifying the loss in grassland area. In addition, large areas of savanna are lost to the Sahara desert every year because of overgrazing and farming (International Sustainability Council, 2013).

Implications for agriculture

Reduction of grassland surface will restrict forage availability for grazing animals, impacting livelihoods and livestock-based systems. In parallel, plant growth will be affected by rainfall variability, altering crop yields. Higher frequency of temporary droughts[4] can also seriously affect crop production. Floods cause direct and indirect deaths as well as livestock and crop losses. In 2000 in Mozambique, flooding and cyclones led to the destruction of one third of total crops (Fleshman 2007, cited in World Bank 2013). Such damages can impact the GDP (Gross Domestic Product). For instance, between 1997 and 2000, Kenya had to face annual damages of 10 to 16% of GDP because of flooding. Furthermore, higher humidity favors diseases spreading. Pests, diseases and weeds are indeed expected to evolve, implying changes of practices for farmers.

Influence on food security

Populations are highly exposed to extreme weather events. For instance, in Mozambique, floods in the Zambezi River Valley displaced 90,000 inhabitants in 2008, some permanently. Furthermore, negative impacts on livestock health may directly affect food and economic security where people depend on the consumption or sale of animals and their products.

The diversity of crop and livestock productions in sub humid Africa is threatened by climate change. So are the livelihoods of populations which rely on these activities. This climate change's major trends are: increase of mean annual temperatures; reduction of rainy season duration; higher spatial and temporal variability of rainfall; more frequent and intense cyclones; more frequent and intense heavy rains; more frequent and intense floods; and more frequent temporary droughts. Such evolutions generate great challenges for farmers, which are summarized in Table 4.

Table 4 - Main challenges for farmers in the sub humid zone regarding climate changes

Affected factor	Impacts on natural resources and production means	Challenges for farmers
Landscape	Shift from grassland to woodland Shift from grassland to desert Sensitivity of herbaceous plants to high temperatures	Loss of savanna grassland
Water	Higher uncertainty about water availability in time and space Lower soil moisture Shorter wet season Reduced soil infiltration of water	Lack of water supply for crops and animals More difficult planning of agricultural calendar

4 Temporary drought: for instance unexpected 15 days of drought during wet season

Soil	Overgrazing	Reduction of soil fertility
Plants	Pests and diseases spreading Weeds spreading Sensitivity of crops to temporary droughts Sensitivity of crops to floods and cyclones	Reduction of crop yields Loss of crops
Animals	Reduction of vegetation diversity and productivity in savanna grass-lands Parasites and diseases spreading Sensitivity of animals to floods and cyclones	Animal feed shortage Reduction of animal productivity Loss of animals
Food security	Destruction caused by extreme climatic events Competition for land Altered animal health Agribusiness extension	Populations displacement Threatened food and economic security

1.3.4 In the humid tropical zone

Agriculture in humid tropical Africa

In humid tropical zones, climatic conditions favor dense vegetation. Food production largely relies on forests, and rice from rain-fed systems is often one of the main staple food-crop (International Sustainability Council, 2013).

Climate changes in humid tropical Africa

Fewer papers exist on climate evolution in humid tropical Africa and its implication for agricultural production than for the other studied zones. Mean temperatures are globally rising while heat waves duration increases. According to the World Bank (2013), no long-term trend for rainfall has been observed in the humid tropical zones, although there should be a decline in mean annual precipitation over tropical rain-forests (Boko et al., 2007). In North Congo for instance, it has decreased of about 3% for the period 1960 to 1998 (Somorin et al., 2010). Rainfall is likely to concentrate in shorter wet seasons, while drought periods extend. In Sierra Leone for instance, prolonged periods of dry days have been observed even during rainy seasons. In addition, higher temperatures and air humidity could provoke heavy rains (Ministry of environment, water and forests of Madagascar, 2006). Indeed, extreme precipitation will very likely become more intense and frequent as global mean temperature rises (Pachauri et al., 2014). Also cyclones frequency has doubled in the last 15 years compared to the 15 previous years in the humid tropical areas of Madagascar (NGO expert, 2015).

Effects on water resources

Paeth et al. (2008) expect a prominent surface heating and a weakening of the hydrological cycle over most of tropical Africa. Water availability could become unequally distributed in the year.

Effects on soils and landscapes

Paeth et al. (2008) underline the influence of land covers on climate in tropical Africa. They estimate that the prevailing droughts in the second half of the twentieth century in tropical Africa were at least partly a consequence of land cover change towards less vegetation. It therefore highly matters to protect land cover in tropical Africa in order to mitigate the drying trend. Also, maintaining a plant cover could mitigate the impacts of heavy rains and cyclones on soils. Such extreme events, which are increasing in frequency and intensity, damage soils and provoke fertility loss.

Figure 9 - Humid tropical climate zone

Implications for agriculture

Longer heatwaves and temporary droughts in wet season could enhance heat stress for crops and animals. Seasonal droughts disrupt cropping calendar of rain-fed systems (Ministry of environment of the Democratic Republic of Congo, 2006). However, tropical plants such as maize, sorghum, millet or sugarcane should be able to adapt. Indeed, Denhez (2007), expect plants which like hot climates to benefit from warming. Gerardeaux et al. (2012) also expect rice growth to be favored by temperature and CO2 concentration increase in Madagascar, although sustainability of rain-fed rice production systems is threatened by rainfall decline. In Western Africa, unprecedented erratic rains have been observed, disturbing the burning and planting while favoring weed infestation. Such rainfall extremes, as well as cyclones, also cause crop destruction (Jalloh et al., 2013).

Influence on food security

Extreme events such as erratic rains can be responsible for infrastructure destruction, affecting food storage and distribution and therefore food security.

Rain-fed and forest-based production systems of humid tropical Africa are threatened by the following major trends of climate change: increase of mean annual temperatures; reduction of rainy season duration; more frequent and intense cyclones; more frequent and intense heavy rains; more frequent and longer temporary droughts during wet season; longer heatwaves. Such evolutions generate great challenges for farmers, which are summarized in Table 5.

Table 5 - Main challenges for farmers in the humid tropical zone regarding climate changes

Affected factor	Impacts on natural resources and production means	Challenges for farmers
Landscape	Reduced vegetation cover	Surface heating and soil moisture reduction
Water	Higher uncertainty about water availability in time and space Shorter wet seasons Lower quantity of available water	More difficult planning of cropping calendar Lack of water supply for crops and animals
Soil	Damages caused by heavy rains and cyclones Reduced vegetation cover Increased soil erosion	Reduction of soil fertility
Plants	Sensitivity of crops to temporary droughts Surface heating Diseases spreading Weed spreading Sensitivity of crops to heatwaves Destruction caused by cyclones Destruction of storage infrastructure by extreme climatic events	Reduction of crop yields Loss of crops Reduction of products shelf life

Animals	Sensitivity of animals to temporary droughts and heatwaves Parasites and diseases spreading	Reduction of animal productivity
Food security	Destruction of infrastructure caused by extreme climatic events	More restricted access to markets

Globally, temperatures are rising and rainfall patterns are becoming increasingly unpredictable over Africa, with regional disparities. Also various extreme climatic events are multiplying in many regions. Climate change effects will most likely compromise agricultural production and access to food in many African countries, while their populations keep growing. Agricultural sector's vulnerability is accentuated by existing challenges for development such as poverty, governance and institutional aspects, limited access to capital, ecosystem degradation and complex disasters and conflicts. Peasants are likely to be the most affected whereas they produce about 90% of total agricultural output in Africa.

Even if global society stopped emitting greenhouse gases today, warming would still be inevitable in the next few decades (IPCC, 2014). There is thus an urgent need to find solutions to reduce peasants' vulnerability. If changes at institutional scale cannot be achieved so easily, it should start with agricultural practices[5]. On the one hand, the agricultural sector contributes to 14 % of greenhouse gas emissions (Branca et al., 2013). On the other hand, agriculture has a great potential of mitigation. Indeed, improved management practices of cropland and livestock could respectively allow for a reduction of CO_2 and CH_4 and N_2O emissions. In addition, carbon sequestration can be enhanced thanks to conservation farming practices, agroforestry, improved grassland management and restoration of degraded lands. The adoption of sustainable agricultural practices could therefore play a major role in climate change mitigation.

Peasants implement agricultural techniques that fit the environment they are producing in. Indeed, they have developed practices that permit to fulfill the needs of crops and animals considering the conditions of availability of natural resources in various regions with a wide diversity of climates, soil types and vegetation. In response to direct and indirect effects of climate change on agricultural productions, farmers may adapt their farming systems in order to keep producing food and ensure food security. Some imagine innovative practices or improve traditional ones to respond to novel climatic conditions. Among the variety of peasant adaptation strategies, we chose to focus on agroecological ones. The following part of the study therefore emphasizes adaptation practices based on agroecological principles.

5 Here "practices" embraces technical and organizational systems implemented by farmers at different scales: the plot, the farm and the territory.

Part 2: Adaptation practices to climate change based on agroecological principles

2.1) Some useful definitions

2.1.1 Adaptation, resilience and agroecology

The IPCC defines **adaptation** as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities". Africa's adaptation is "not an option but a necessity" (IPCC 2007, p.452). As climate trends are evolving, it will become increasingly important to put adaptation measures in place in order to manage and reduce the risks of such changes for agriculture and to build resilience. It is the only effective option for societies to face the inevitable impacts of climate change that mitigation cannot reduce (IPCC, 2014).

An agroecosystem may be resilient by itself, if we let interactions between its component take places without disturbing them (NGO expert). Resilience is defined by the IPCC (2012) as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structure and functions."

Agroecology is based on the application of ecological concepts and principles to agricultural production for the optimization of agroecosytems, adding value to local resources with minimal reliance on external inputs. It aims at maintaining or mimicking natural balances while re-placing the farmer at the core of the production process. Agroecosystem management relies on traditional knowledge through participatory approaches. According to Pretty (Pretty 1995, cited in Altieri 2002), the basic principles of agroecology are:

- enhancing biomass renewal and optimizing nutrient availability and balance of nutrient flows;
- ensuring favorable soil conditions for plant growth (organic matter management, soil cover, improvement of biological activity in the soil);
- minimizing losses in solar energy, air and water;
- promoting genetic diversification of species in time and space;
- adding value to favorable biological interactions.

Agroecology also includes social and economic principles:

- social organization and local knowledge transmission
- guarantee of decent revenue for farmers and their families

The agroecological approach is thus multidimensional and can be applied at several scales: the plot, the farm and the territory, always keeping in mind a holistic view.

2.1.2 How is agroecology relevant for adaptation to climate change?

Agroecological practices have a great potential for adaptation to climate change because they allow for adaptation of agricultural production to novel climatic contexts, increasing familial farm's resilience. Indeed, they are in harmony with the local conditions of the agroecosystem they are implemented in.

In addition, general conditions of implementation of agroecological practices may fit African smallholders' environments. Indeed, they rely on low capital and important labor force. Such working force is often available on small farms managed by families, whereas capital is generally very restricted. It thus appears feasible for smallholders to put in practice sustainable agroecological innovations. Furthermore, many African farmers already implement sustainable practices. They typically manage risk through diversification, which is a basis of agroecology. Spreading risks between different crop productions, in time and space, permits to ensure food supply or revenue in case of crop failure. Higher temperatures may allow shorter but more frequent crop cycles within a year (World Bank, 2013). Crop rotations would therefore take advantage of novel climatic conditions. Diversification could permit to compensate for potential losses engendered by climate change. The spreading of such techniques would be facilitated by existing local traditional knowledge on sustainable agricultural practices. Agroecology therefore appears as a realistic approach for adaptation strategies to climate change.

2.1.3 Peasant agriculture

In Africa, the majority of farms are managed by families. We will thus put an emphasis on small-scale peasant farming systems, which are being promoted by international organizations for rural development and fight against poverty. Peasant farming is based on a long term vision, including environmental risk management to reduce farms' vulnerability to possible shocks and ensure a minimum production in spite of climatic constraints. Smallholders therefore aim at preserving natural environment while using its functions. First, they cultivate species with various characteristics and agronomic needs. This biodiversity constitute a natural barrier against parasitism and weeds. Small-scale farmers also contribute to landscape preservation, through the maintenance of hedges, uncultivated areas, etc. Reasonable size of herds allow for preservation of grasslands and woody pasturelands which act as carbon sinks. In addition, they integrate crop and livestock productions, maintaining and sometimes improving soil fertility and tending towards autonomy. Secondly, peasant systems rely on very low use of chemicals. Such economic systems and the reliance on natural biological cycles allow limiting impact on water resource. Finally, smallholders' farming systems are generally well inserted in local economics, which strengthen local food systems that are essential to face climate changes. All these mechanisms contribute to carbon sequestration and limitation of greenhouse gas emissions while favoring peasant agriculture's adaptation (Confédération paysanne, 2015).

2.1.4 The innovation process in agricultural systems

Adaptation strategies include innovation in agriculture. Innovation is defined as the application of resources and technological, institutional and human findings to production, generating new practices, new products and markets, new institutions and organizations with increased efficiency (Poole, 2006). The sources of innovation are multiple: they emerge among farmers, or emanate from research bodies or development organizations. In all cases, all these actors must combine their efforts, in a collective and interactive process, to consolidate the initial concept; to adapt it to the diversity of environments and farms; and determine its area of validity (Meynard and Casabianca, 2011). Conditions required for an innovation must be checked, as well as its economic, social and environmental effects in the diversity of situations encountered.

According to the World Bank (2006), innovations generally consist of many small improvements in a continuous amelioration process, rather than of radical improvements. Those progressive localized improvements can be difficult to detect. Furthermore, transformations may be considered as innovative or not depending on the point of view. Practices may be innovative in a given context whereas they have been implemented for a long time in another one.

General improvements in current agricultural management techniques are essential for short and long-term increase in yield productivity, especially in a world that is changing rapidly. Innovation may contribute to anticipation, adaptation and appears as a way to remain competitive or even to survive. It implies diverse changes of practices that spread in farmers communities (Vall et al., 2014).

2.2) Agroecological adaptation strategies in the four zones of study

Innovations based on agroecological principles that are already implemented by peasants in their adaptive strategies are studied. Presented practices may not be specifically implemented to face climate change effects, but they all contribute to enhance farming systems' resilience to those evolutions. An overview of agroecological innovations in each of the referent farming systems is given, at different scales: the plot, the farm and the territory[6]. In addition, a glossary of agroecological practices can be found in Appendix 8. As presented in part 1, agroecological principles principally rely on landscape management, water management, soil fertility management, seeds and plants management, and animal management. The practices that have been inventoried through interviews and literature review will therefore be classified according to these agroecosystems' components. In addition, strategies of production valorization to ensure farmers with decent revenue, and social organization and knowledge transfer will be briefly presented.

2.2.1 Characterization of relevant systems of study[7]

As mentioned before, a referent farming system has been identified for each of the four zones of study. We chose to focus on systems that are broad enough to include a diversity of situations. They are farming systems, meaning that they include not only the production at the farm scale, but a broader frame (processing, commercialization…etc.). The FAO (2001) defines a **farming system** as "a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate". The referent systems were chosen according to two criteria: their representativeness and their reliance on agroecological principles.

As we can see in **Figure 10**, in the arid zone, sparse vegetation prevails (number 13 on the map). That is why sophisticated systems have been designed to adapt to difficult climatic conditions: the oasis systems, which have been selected for the arid zone.

Regarding the sub-arid zone, we can see on the map that we find principally agropastoral millet/sorghum systems and cereal-root crop mixed systems (numbers 11 and 8 on the map). It therefore appears relevant to study agropastoral systems for this zone.

In the sub humid zone, we observe on the map a predominance of root crop, maize mixed, cereal-root crop mixed and forest-based systems (numbers 8, 9, 7 and 3). Considering the importance of livestock for livelihoods, the study will focus on mixed crop-livestock systems for this zone.

Finally, in regions under humid tropical climate, tree crop, forest based and rice-tree crop systems prevail (numbers 2, 3 and 4). We will thus study agroforestry systems in the humid tropical zone.

2.2.2 Oasis systems of arid regions

What characterizes an oasis system?

Oases are "islands of prosperity" in an arid environment, which can host intensified agroecosystems. They are places of settlement and intense economic and socio-cultural activities which are estimated to constitute a living for 10 million people (Deygout and Treboux, 2012).

In Africa, oases are found in the Saharan region, where they developed with caravanned trade. They remain quite traditional in their cultivation system.

A specific cultivation design in several strata creates the "oasis effect", which is a microclimate based on reduction of temperature in an isolated moisture source surrounded by an arid area. Humidity, heat and light allow for space optimization in an environment of high thermic amplitude where fertile soils and water lack. Indeed, oases host a biodiversity adapted to specific climatic constraints and thus constitute a great reservoir of local genetic diversity.

6 Territory: a particular area used for or associated with a specific individual or activity (Houghton Mifflin Harcour, 2014)
7 References will be presented as follows:
Information from the literature: (Author, year)
Information from the interviews: (NGO expert)

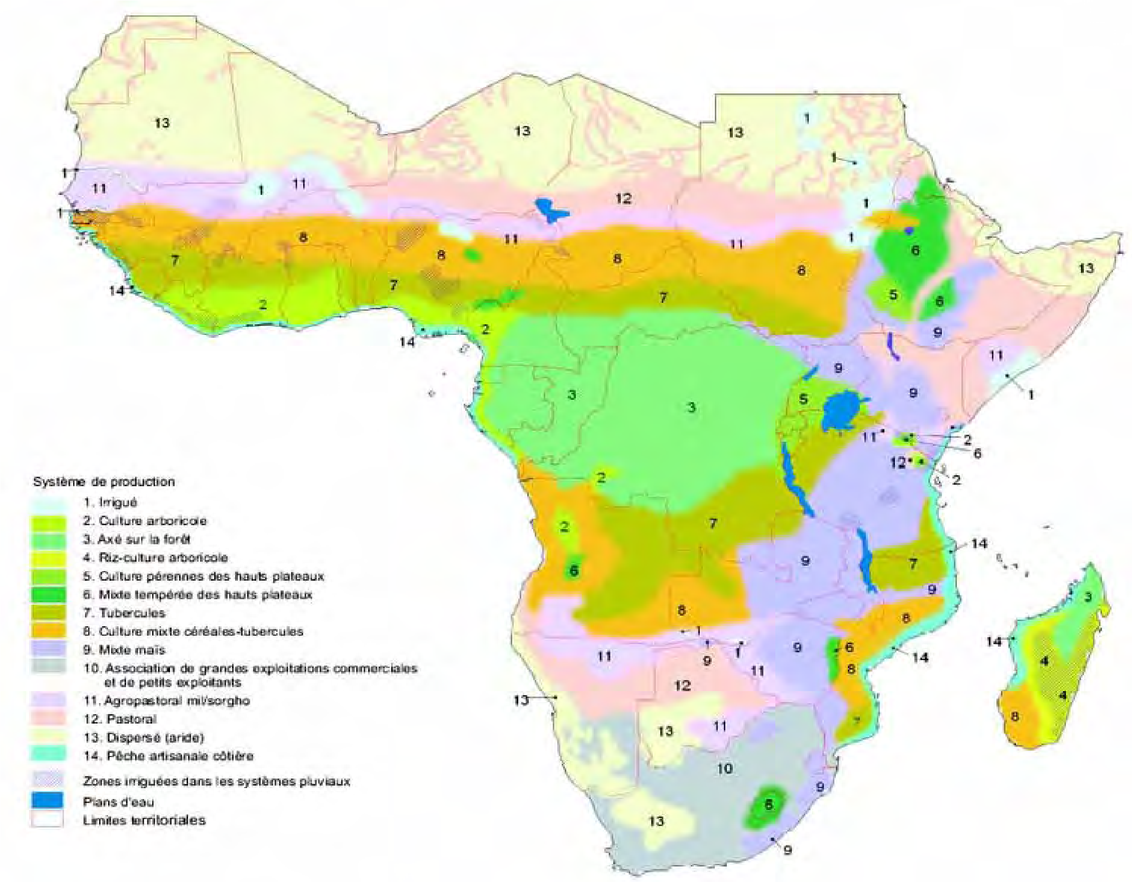


Figure 10 - Major farming systems in Sub-Saharan Africa

(Source : FAO, Farming systems and poverty : improving farmers' livelihoods in a changing world, FAO, 2001, p.31)

Diversified agricultural production is distributed in the different vegetative strata:

- The tree layer: date palm, whose leaves filter the sunlight
- The shrub layer: mainly vines and fruit trees (pomegranate tree, apricot tree, etc.)
- The herbaceous layer: cereals, alfalfa, vegetables, medicinal and aromatic plants

The core of the oasis hosts intensive irrigated cultivation based on submersion specific systems that do not use fossil energy and rely on available water under tree layer. Extensive livestock production is led on large pastoral areas surrounding the palm grove. Oases also constitute a relay for nomad and semi-nomad breeders of arid zones. Animals contribute to soil fertility management while benefiting from oasis forage production (Cheneval and Michel-Queirel, 2012). Additional recession crop production can be practiced in some areas although it is quite unpredictable (Deygout and Treboux, 2012).

Oases provide with a wide range of foods including cereals, legumes, milk products and animal proteins, which contribute to food security and nutritional quality of local populations' diets.

Why a focus on oasis systems?

To which extent are oasis systems resilient regarding climate change?

In arid zones, climate changes accentuate water scarcity and soil degradation and affect agricultural yields. Oases have a great potential to face such challenges. They represent real models of adaptation to tough climatic conditions, with characteristics of flexibility to face climatic shocks. Indeed, oasis farmers have been able to adapt in response to droughts in the 1970's and 1980's, which have caused a decline of agricultural production and losses in livestock. Oases have shown their resilience through several adaptation measures including a diminution of the number of cultivated layers, sales of animals and multiplications of wells.

Which representativeness of oasis systems?

Oases constitute the agroecosystem which host the most people (NGO expert) and counts for the majority of the Utilized Agricultural Land in arid zones (Cheneval and Michel-Queirel, 2012). We observe an increasing interest from governments and international organization for these farming systems.

Figure 11 - Oasis in Morocco
(Source : CARI, 2006)

How are oasis systems agroecological?

Oasis systems rely on agroecological principles: the multiple layers optimize the use of surfaces and take advantage of beneficial interactions between plants; crop and livestock integration adds value to the interactions between plants and animals. Diversification of production, including trees, bushes and grasses, strengthens the resilience. For instance, if cereal production, which is more sensitive to climate change, fails, other productions such as fruits may be able to compensate. This diversity also enables the production of forage for animals, relatively compensating the lack of pastures. Oases should therefore constitute a great advantage for food security of rural populations in the coming years if they are well maintained.

Which advantages of oases?

Thanks to an optimized utilization of soil and water resources and productions adapted to the environment, oasis cultivation gives high yields. Also, these family farming systems aim at preserving production means and increasing resilience. Indeed, the oasis system is designed to be able to absorb brutal shocks and quickly recover equilibrium. This is mainly due to its functioning, its familial organization and its environment. Humans have had to innovate, adapt and sustainably manage resources, in order to produce more with fewer resources and be able to survive in arid areas. Moreover, oases' sophisticated design allows for diversification of production and risks. Such farming systems present a potential for job creation. Their diversified products also potentially give access to broader market. Collateral activities such as processing and sale are often restricted or relocated whereas they could be developed and profit to local population.

Which socio-economic factors threaten oasis systems?

Besides climatic constraints, oases are subject to several socio-economic threats. First, groundwater tables are overexploited because of uncontrolled multiplication of pumping stations. Secondly, oases maintenance is weakened by migrations which are stimulated by climate change. Indeed, workers are leaving, restricting the available work force. This phenomenon, combined with the lack of organization and professionalization of producers, contributes to the degradation of oasis maintenance and productivity. Furthermore, nowadays farmers' incomes mainly rely on their pluriactivity and money transferred by migrants. This system is not economically sustainable because it is dependent to external financial inputs. In addition, knowledge and know-how are progressively disappearing, instead of being transferred between generations. Further recognition of oasis specificity by public policies would be required. Finally, production modes are becoming more and more individual, with the emergence of large modern palm groves controlled by external investors. Such farms represent further unfair competition for water for smallholders.

Agroecological innovations for adapting oasis systems to climate change

Table 2 presents the main challenges of climate change for farmers of arid Africa which have been mentioned in the expert interviews. Such evolutions threaten oasis systems. They may be partly faced by a set of practices that have been mentioned in the interviews and in the literature and are summarized in Appendix 4. They are classified according to the previously identified components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow).

These agroecological practices are then classified according to the scale they are implemented at, in **Figure 12**. The determination of the scale(s) of **implementation** of each practice is subjective and could be different if approached with another point of view.

Figure 12 shows that agroecological innovations in oasis systems have been inventoried at the three scales: the plot, the farm and the territory. However, they seem to focus more on farm scale (47% of inventoried practices) and plot scale (42%). Peasants may focus on the interactions taking place inside their oases rather than on those with the external environment. Oasis production is based on practices that favor beneficial interactions between different species. Farmers therefore strengthen their systems by further stimulating these interactions.

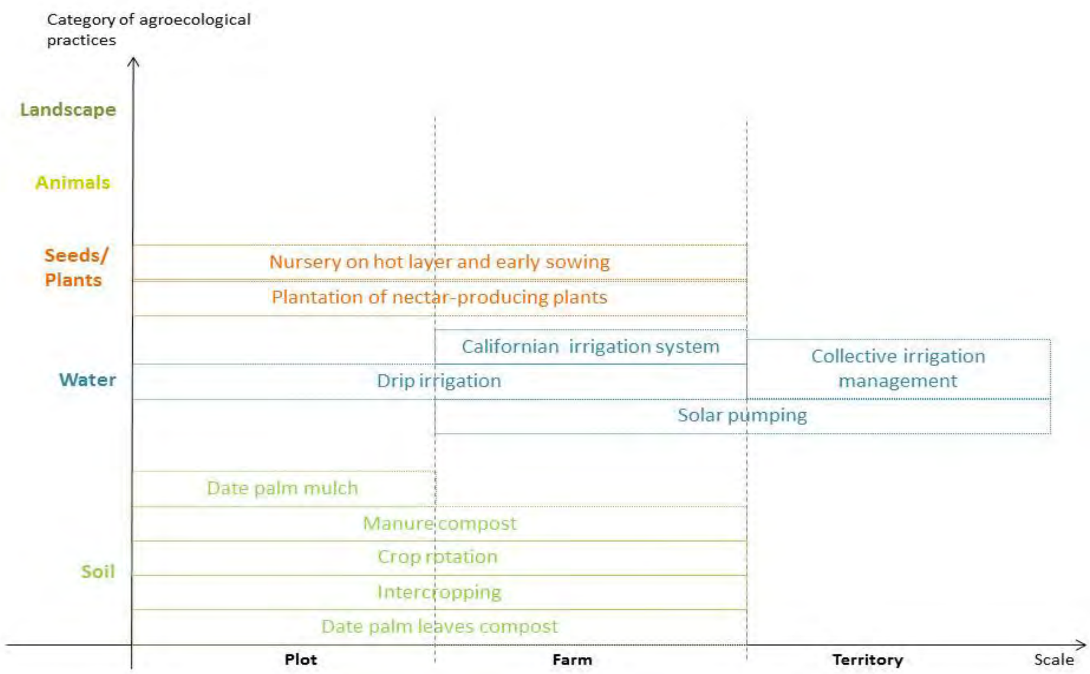


Figure 12 -Scale analysis of agroecological innovations in oasis systems

Regarding the different agroecosystem's components, we can see that these innovations principally focus on the soil (46% of inventoried practices) and water resource (35%). Inventoried practices appear to be directed directly to the management of resources for plants alimentation in the palm groves. They aim at diversifying soil fertilization as well as improving water use efficiency. Although practices of animal management have not been inventoried in this study for oasis systems, they may still be of major importance for peasants in arid areas. Furthermore, even though farmers' collective organization does not appear as a principal strategy for improving oasis systems, some innovations are implemented at organizational scale.

Inventoried strategies of collective organization and production valorization

In the study zone, oasis farmers also implement strategies to add value to their production. They gather to process and sell their products: they create **processing plants** and **cooperatives**. Some producers valorize their production through **short food supply chains** such as direct selling and fairs. Another strategy is to get their **products labelled**: some oasis farmers produce organic henna; others dates with a Demeter certification. These practices at organizational scale are included in **Figure 13** below as they can be considered as agroecological innovations that may contribute to adaptation to climate change. Indeed, such collective improvements are essential for farmers to increase their resilience to climatic shocks.

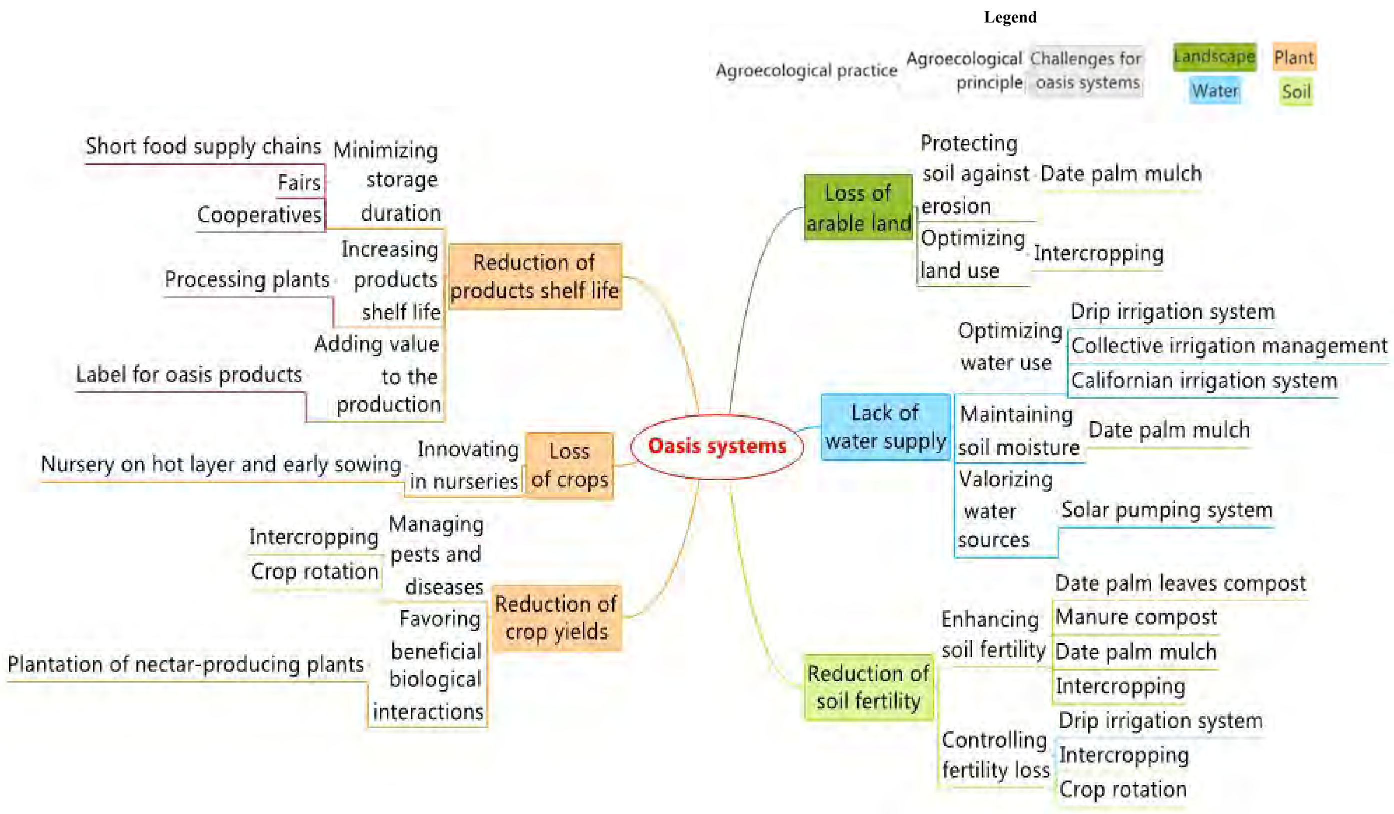


Figure 13 - Challenges to oasis farmers and agroecological practices

Figure 13 presents the link between identified challenges of climate change to oasis systems and inventoried agroecological practices. We can see that for each of the major challenges posed by climate change to oasis farmers (identified in part 1 of the study), there plenty of agroecological practices inventoried responding to it.

Analysis of peasant strategies of adaptation to climate change

The inventoried agroecological innovations contribute to strengthen oasis systems. Techniques of efficient irrigation (drip irrigation system, Californian irrigation system, collective irrigation management), sustainable water pumping (solar pumping system), and humidity maintenance (date palm mulch) can better valorize scarce available water resources. Furthermore, practices that enhance soil fertility (date palm leaves compost, manure compost, intercropping such as wheat-alfalfa association, crop rotations) and protect from erosion (date palm mulch, drip irrigation system) are implemented in order to control fertility loss. In addition, peasants modify their practices of crop management to adapt to novel conditions of soil fertility and water supply. They improve sowing conditions (nursery on hot layer and early sowing) and favor beneficial interactions between plants and insects (intercropping, planting of nectar-producing plants). Finally, collective organization of farmers (short food supply chains, fairs, cooperatives, processing plants, and label for oasis products) allow to better valorize their production while ensuring food security of local populations. Peasants' strategies respond to the major challenges of soil fertility loss and reduction of water supply.

Oasis systems have to face major challenges of water supply and soil fertility degradation, which are accentuated by climate change. These systems present characteristics of flexibility which should allow them to adapt to more and more restrictive conditions. The inventoried agroecological innovations contribute to strengthen these characteristics. Techniques of irrigation and humidity maintenance must allow to add value to scarce available water resources. Furthermore, practices that enhance soil fertility and protect it from erosion are implemented in order to control accelerated fertility loss. In addition, peasants modify their practices of crop management to adapt to novel conditions. Finally, collective organization of farmers must allow them to better valorize their production while ensuring food security of local populations.

Oasis systems therefore present adaptation opportunities to climate change based on agroecological principles.

2.2.3 Various levels of crop-livestock integration in sub-arid and sub humid regions

In Africa, livestock has a great importance for social, economic and environmental aspects. Animal breeding allows for valorization of pasture land which represents 78% of total agricultural surface on the continent (Vall et al., 2014); and significantly contribute to food security, reduction of poverty and job creation. Small-scale livestock farming communities take advantage of human-inedible forage and marginal lands, to produce high quality and human-edible foods; and avoid degradation of natural resources and social arrangements (Rivera et al., 2012).

In Africa, livestock breeding depends on direct feed supply of spontaneous and cultivated vegetation. Its mobility is therefore linked to vegetation spatial repartition which depends on rainfall and temperatures. As presented in **Figure 14**, there exist a diversity of livestock systems. In sub-arid zones, breeding is strongly dependent to natural resources and mobility. Pastoral systems that practice transhumance therefore prevail. In sub humid regions, livestock husbandry has relatively settled as climatic conditions allow for crop cultivation. Mixed crop-livestock systems are thus dominant. Finally, in the two zones, intermediary systems, which associate mobility and crop productions, are developing: agropastoral systems. We will put an emphasis on agropastoral systems of sub-arid zones in order to study integration of crop and livestock productions which is a basic principle of agroecology. Regarding sub humid zones, we will focus on mixed crop-livestock systems.

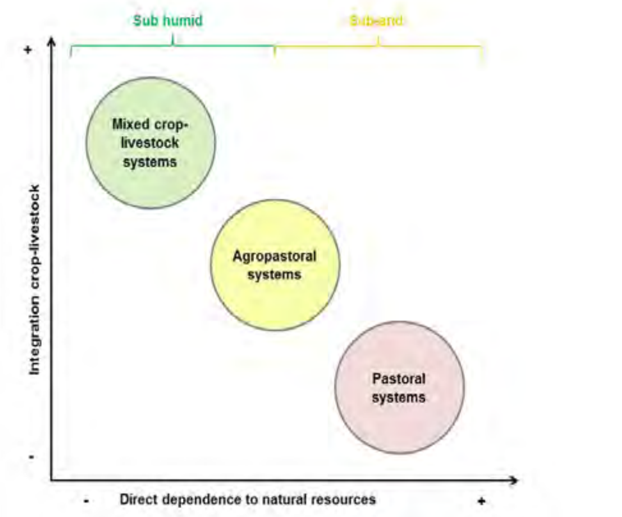


Figure 14 - Levels of crops-livestock integration **(adapted from INRA, 2014)**

2.2.4 Agropastoral systems of sub-arid regions

What characterizes an agropastoral system?

A diversity of agropastoral systems

There exists a great diversity amongst agropastoral systems, with a wide range of mobility levels, herds' sizes and cultivated surfaces. In Africa, they are generally found in regions with low density of population. One reason is that herds' mobility is a necessary condition for the systems' viability, as it gives access to resources of water and pastures whose spatial distribution varies along the year. Breeders may also have access to cultivated land through their family or agreements with crop producers. It may be very interesting for agropastoral farmers to work at territorial scale.

D'Aquino et al. (1995) underline the importance of the emergence of systems combining crop and livestock production. In areas that have been historically dedicated to cultivation, resources have often been overexploited, leading to yield decreases. In response, farmers generally diversify their production with animal breeding. Animals must provide food for auto consumption, additional income, fertilizer and animal power and also have social functions. In agropastoral systems, livestock is a patrimony and material security insurance, as well as a symbol of success (Dicko et al., 2006).

Figure 15 - Agropastoral system in Niger
(Source : CARI, 2007)

Dicko et al. (2006) present a classification of agropastoral systems in the Sahel. They distinguish the associations dry crops-livestock (with millet/cowpea or millet/peanut); irrigated crops-livestock (with irrigated or rain-fed rice); and the agrosilvopastoral system (with Acacia Senegal). The millet/cowpea agropastoral system is located mainly in south Mali, southwest Burkina Faso and Niger and North Nigeria. The system mil/peanut is found in north Senegal and in almost whole Gambia. The agropastoral systems linked to irrigation and rain-fed crops is implemented in the delta of Niger River in Mali, along Niger and Senegal Rivers and around the Lake Chad. Finally, the agrosilvopastoral system based on Acacia Senegal is practiced mainly in Sudan (Dicko et al., 2006).

How is livestock managed in agropastoral systems?

Agropastoral herds are rather small compared to those of pure transhumant systems, and composed mainly of sheep, goats and bovines from local breeds, with variable productivity. Milk is the main animal product in the Sahel, in particular bovine one, although farmers do not necessarily have access to markets to add value to their production (NGO expert). However, goats quickly spread after the droughts in the Sahel thanks to their aptitude to better exploit degraded lands, their short reproduction cycle and the fact that smallholders can easily acquire them. Breeders can also easily sell them in order to buy other animals and diversify the system (Dicko et al., 2006).

Herds can be owned individually by a family, or collectively, and are often managed by an employed shepherd. The shepherd is in charge of daily management of cattle while women generally take care of small ruminants.

Livestock can be managed through transhumance or more sedentarily (range pasturing, divagation, tether or "zero-grazing"). Transhumance is practiced mostly with bovines. It is planned and accompanied only by the herdsman while dairy animals stay at the permanent place. In wet season, transhumance is practiced towards the driest areas, to leave arable land available for cultivation. This itinerary permits to exploit quality insect-free pastures. Then, at the beginning of the dry season, herds move back to the permanent place. Regarding small ruminants, the system is more sedentary. In the wet season, herds are either brought on fallows with a herdsman, or let tethered to a post on family land. During the dry season, the divagation system prevails (Dicko et al., 2006).

Why a focus on agropastoral systems?

To which extent are agropastoral systems resilient regarding climate change?

Generally, climate change impacts more severely livestock farming in those regions with higher temperatures and lower levels of development, particularly in marginal lands (Rivera, 2012). Warming destabilizes precipitation patterns which then disrupt primary biomass production and filling of water reservoirs. Water availability increasing unpredictability impacts crop and livestock productivity and influences animal mobility. Breeders have to move back earlier to cultivation areas. This phenomenon leads to an overexploitation of grasslands in some areas, whereas pastures are under exploited in others, which provokes further degradation (NGO expert). In addition, arable land availability is further decreasing. Warming restricts the area suitable and heavy rains cause erosion that affects land fertility. Such evolutions also affect the availability of feeds for animal husbandry, as they cause yield reductions, including of millet. Livestock production is also affected by climate changes through heavy rains that favor diseases propagation (NGO expert). In addition, successive years of extreme drought decimate herds and prevent their reconstitution. More frequent weather extremes may also destroy physical infrastructure for crops and livestock (Rivera, 2012).

The environmental crisis provoked by the drought in 1972-1973 affected livestock production in several ways: degradation of livestock itinerary, loss of herds, migration of populations to sub humid zones. However, farmers were able to reconstruct their systems. Moreover, this event conducted to the international recognition of the vulnerability of this region and the necessity to take action to restore its production functions and prevent future disasters (Dicko et al., 2006). Agropastoral systems present several aspects of resilience to climate change. First, their mobility allows optimizing land use in accordance with climatic constraints (NGO expert). Heterogeneity of sub-arid zones, generally perceived as a production disadvantage, is actually the basis of mobility which is the optimal use of these ecosystems (Wezel, 2014). Furthermore, having several types of productions permits to diversify climatic risks as they are not sensitive to the same factors. Such systems also often include a variety of species, whose needs and life cycles differ in time, increasing their flexibility and diversifying the risks. They generally rely on the maintenance of hardy local breeds of animals that are resistant to poor diets and water lack. Also, in case of economic or environmental crisis, breeders may sell animals to ensure their food security. Finally, breeders often show a great capacity of negotiation which allows them to a certain extent to take advantage of opportunities to graze their animals while creating alliances that strengthens their systems (NGO expert). Nevertheless, agropastoral systems' resilience is sometimes insufficient and farmers sell capital that they should keep (NGO expert).

Which representativeness of agropastoral systems?

Agropastoral systems are representative of peasants' activities in sub-arid zones and concern large numbers of population (NGO expert). They represent the main wealth of the region and constitute one fundamental social value. Even though peasants in sub-arid regions cannot always afford to breed animals, large parts of the population depend on agropastoral systems. Indeed, many households rely on livestock for food, animal products, income or insurance against crop failure. For instance, in the sub-arid zone of Madagascar, zebus are traditionally integrated in farming systems for transport and manure supply (NGO expert).

How are agropastoral systems agroecological?

Agropastoral systems rely on agroecological principles including fertility transfer from animals to fields (in case of high number of animals and limited cultivated surfaces); the use of local resources and their collective management (NGO expert); low dependence on external inputs; and the maintenance of sensitive zones. Agropastoral systems are based on traditional know-how and knowledge transmission between farmers (NGO expert).

Which advantages of agropastoral systems?

Agropastoral systems can bring responses to the challenges of climate change. Integrating crop and livestock production permits to take advantage of their interactions. Animals bring organic manure that contributes to crop fertilization and thus to yield increase. Higher amounts of crop products (forage, byproducts and residues) lead to a better alimentation of animals, which in return bring more manure and work force for cultivation and transport. This integration permits to maintain crop production, which is impacted by climate change, while ensuring another production in case of crop failure. In addition, breeding permits to make use of remote lands on which crop cannot be grown and of residual resources. It also generates jobs in the dry season, when work force required for cultivation is low. Dicko et al. (2006) state that livestock farming sustainability in the Sahel will depend on the integration between crop and animal production. Furthermore, population growth and urbanization also contribute to increasing animal products demand and to the multiplication of markets and local trade of livestock products. Furthermore, agropastoral systems host various innovations, such as livestock diversification, use of woody forage resources, hay fabrication and organization of pastoral itineraries (NGO expert).

Which limits of agropastoral systems?

Agropastoral systems present some limits though. First, there might be a competition for allocation of resources between crop and livestock productions. Indeed, agricultural work during wet seasons may limit animal breeding during this period. Animals may be placed in available lands that are degraded by the lack of control over grazing. Moreover, small ruminants generally do not provide with sufficient manure for cultivated land fertilization.

Which socio-economic factors threaten agropastoral systems?

Agropastoral systems in sub-arid zones are also threatened by socio-economic factors. Herds' mobility is constrained by crop cultivation expansion and pasture paths degradation. This situation often leads to conflicts linked to land and water availability but also to damages caused by animals on fields. Reduced herds' mobility generates feeding issues in periods when they didn't exist in the past (Vall et al., 2014).

Agroecological innovations for adapting agropastoral systems to climate change

Table 3 presents the main challenges of climate change for farmers of sub-arid Africa. Such evolutions threaten agropastoral systems. They may be partly faced by a set of practices that have been mentioned in the interviews and in the literature and are summarized in Appendix 5. They are classified according to the previously identified components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow).

These agroecological practices were then classified according to the scale they are implemented at, in **Figure 16.**

Figure 16 shows that agroecological innovations in agropastoral systems have been inventoried at the three scales, although they seem to focus more on territorial (41% of inventoried practices) and farm scale (38%). These results seem in accordance with the fact that farmers have to organize their practices at territorial and farm scales to plan animals' displacements and cultivation.

Regarding the different agroecosystem's components, we can see that the majority of inventoried practices concern animal management (56% of inventoried practices). Farmers compensate for the lack of forage by producing alternative feeds, exploiting new resources and organizing transhumance more efficiently. In addition, soil fertility management seems to be well addressed, through enhanced soil fertilization and practices that limit soil erosion (26% of inventoried practices). To a lower extent, some practices also focus on water management (7%) and plant management (7%), but farmers seem to focus principally on the access to pastures and feeds and the maintenance of cultivated soils' quality. Furthermore, farmers innovate at organizational scale, to better valorize their production.

Inventoried strategies of collective organization and production valorization

In sub-arid Africa, farmers also implement strategies to valorize their production. Some take part in **short food supply chains** that allow them to get a better price while getting closer to their clients. Breeders with dairy production may take part in **milk collection systems** to add further value to their production and ensure access to outlet. Some meat producers gather to **develop the sector**, in order to strengthen their production mode and stimulate their revenue while getting closer to their fellow breeders. These innovations are included in **Figure 17** below as they can be considered as agroecological innovations that may contribute to adaptation to climate change.

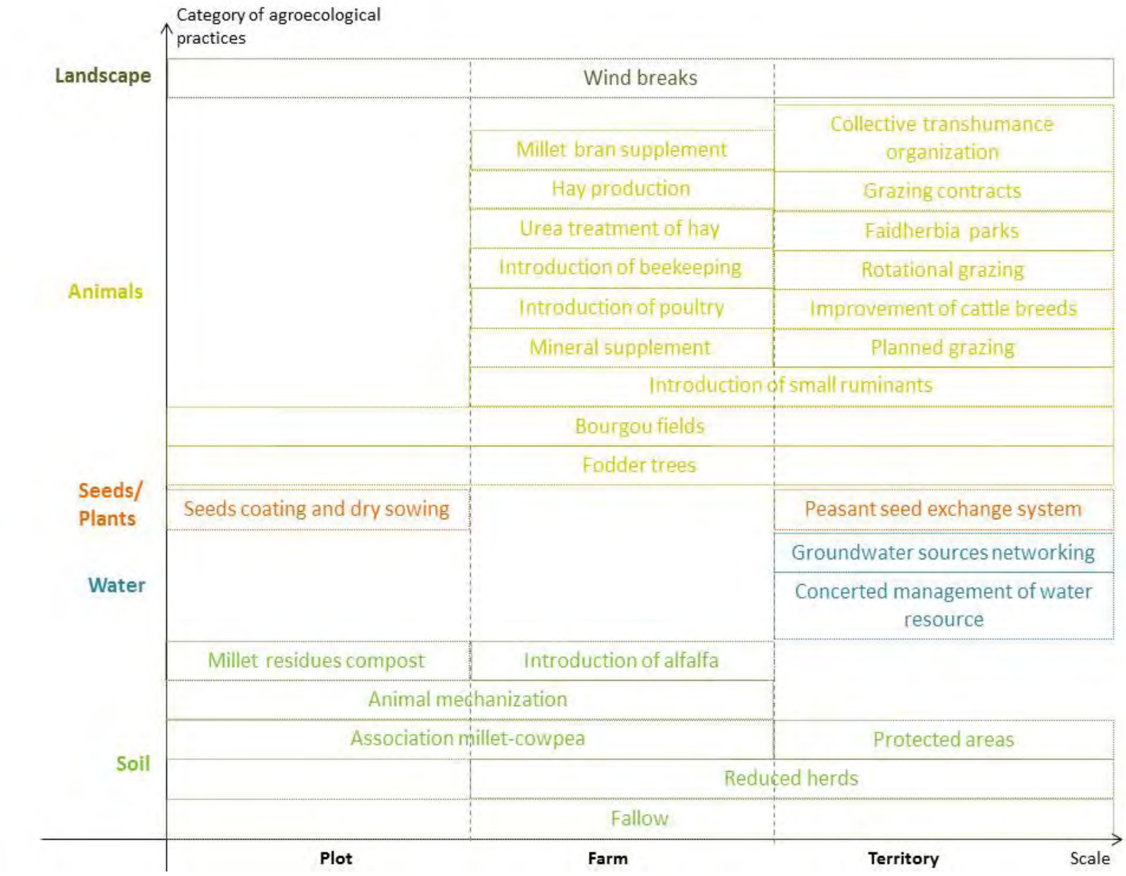


Figure 16 - Scale analysis of agroecological innovations in agropastoral systems

Figure 17 presents the link between identified challenges of climate change to agropastoral systems and inventoried agroecological practices. We can see that for each of the main challenges posed by climate change to agropastoral farmers, there are plenty of agroecological practices inventoried responding to it.

Analysis of peasant strategies of adaptation to climate change

The inventoried agroecological innovations contribute to strengthen agropastoral systems. Farmers manage increasing water availability uncertainty through different strategies: they collectively optimize use of available water (concerted management of water sources, groundwater sources networking); they grow more resistant crop varieties and animal breeds (peasant seed exchange systems, improvement of cattle breeds); they adapt their cultivation practices (seeds coating and dry sowing); and they diversify the risks (association millet-cowpea, introduction of small ruminants, introduction of poultry, introduction of beekeeping). In addition, smallholders try to limit the loss of arable land surface and quality by controlling soil fertility loss (protected areas, wind breaks, fallow) and improving fertilization (association millet-cowpea, introduction of alfalfa, millet residues compost, Faidherbia parks, and grazing contracts). They also compensate for the reduction of forage availability by improving feed rations (urea treatment of hay, mineral supplement, millet bran supplement); producing alternative feeds (introduction of alfalfa, Faidherbia parks, hay production, fodder trees, Bourgou fields); and organizing collectively animal transhumance more efficiently (reduced herds, collective transhumance organization, planned grazing, grazing contracts, rotational grazing). Finally, farmers organize themselves collectively to add value to their production (short food supply chains, milk collection systems, meat sector development), which can partly compensate for the loss caused by climate changes.

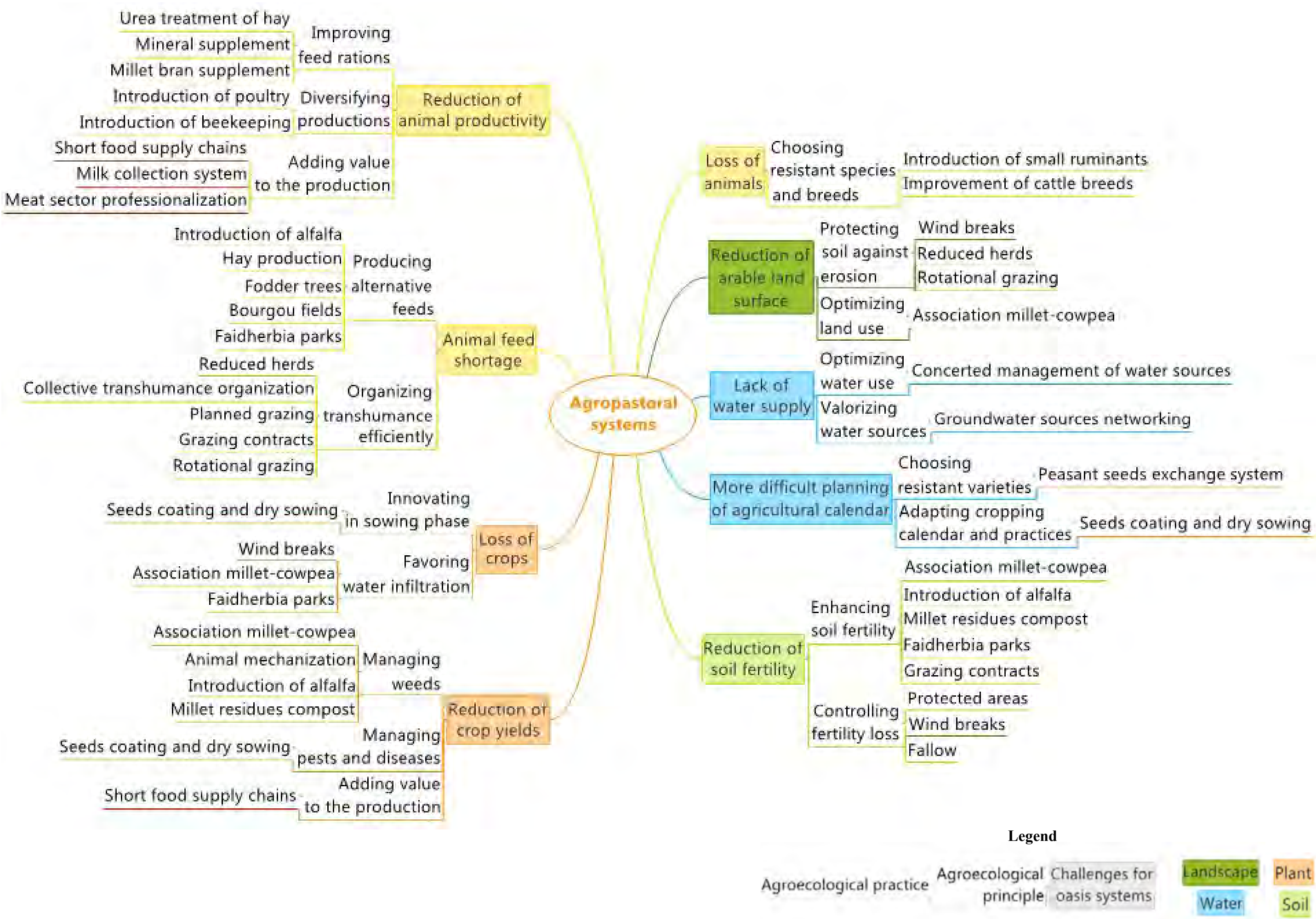


Figure 17 - Challenges to agropastoral farmers and agroecological practices

> **In subarid regions, farmers of agropastoral systems have to deal with increasing uncertainty about water availability in time and space and with a reduction of surface and quality of arable land. Evolutions of rainfall patterns influence available vegetation for animal feeding. Inventoried agroecological innovations contribute to strenghten these systems' flexibility. In response to the effects of climate change, some smallholders work collectively to optimize water resources management. They also adapt their practices to deal with water scarcity and to enhance soil fertility. In addition, farmers compensate the loss of spontaneous vegetation with the production of alternative feeds and an improved management of transhumance. They compensate for animal productivity reduction by adding value to their production and diversifying it. Agropastoral systems therefore present adaptation opportunities to climate change based on agroecological principles.**

2.2.5 Mixed crop-livestock systems of sub humid regions

What characterizes a mixed crop-livestock system?

A diversity of mixed crop-livestock systems

Major farming systems of sub humid zones identified by the FAO (Cf. p.27) all include animals, to different extent. In root crop and maize mixed systems livestock is strongly integrated, whereas herds are more anecdotal in cereal-root crop mixed and forest-based systems. Root crop farming systems, which extend from Sierra Leone to Cameroon, accounted for about 16% of cultivated area and 11% of farming population of Sub Saharan Africa and contained about 17 million cattle in 2001 (FAO). Maize mixed farming systems also include cattle as main livestock, with close integration of crop and livestock productions: animals bring power and fertilizer while crops provide with feeds. Although livestock density is higher than in any other production system in the region, most farmers cannot afford to breed many animals. Only when space opening allows it, bovine breeding is favored (D'Aquino et al., 1995). In regions where tripanosomiasis limits cattle-based systems, smallholders generally introduce small ruminants into their mixed systems. In such systems, integration between crops and livestock productions is limited by restricted amounts of manure.

How are crops and animals managed in mixed crop-livestock systems?

Farmers implement different kind of strategies. Some alternate between cultivation and pasture on the same plot; some rely on crops that they produce and their byproducts for livestock feeding; some graze animals under plantations; and some strategies rely on the combination of several of these techniques.

In areas that are not saturated, farming systems are often based on slash-and-burn techniques, in rotation with fallow of variable duration for pastoral use. Such systems rely on high availability of space which allows for a rest period of about 10 to 30 years that permits to restore soil fertility. They may be replaced by others with stronger integration of crop and livestock productions as competition for land extends.

In some regions with more saturated land, farmers rely on close crop-livestock integration for fields' fertilization and animal feeding. They feed animals on crops they produce and their byproducts and enhance soil fertility with manure.

Mixed systems may also rely on perennials or trees. (cash crops production and subsistence crops for own consumption). In regions where plantations are almost exclusive, subsistence farming is in deficit and animal proteins supply may be of high interest for populations. The association between livestock and plantations is diverse, depending on cultivated plant nature and cultivation mode. For instance, in South of Benin, Cameroun, Côte d'Ivoire and Togo, we can find small ruminants and some cattle in palm groves and coconut. Having animals graze under plantations adds value to herbaceous cover under plantation. Animals "clean" the land and contribute to reduce plantation maintenance cost while manure organic supply favors soil biological activity which is often weakened in plantations by pesticides and herbicides. This fertilization is completed with compost made of perennials' leaves.

In more humid forest areas, animal breeding is limited by vegetation density which restricts animals' movement and favors parasites and diseases spreading. There are though some small ruminants grazing in undergrowth where vegetation opening allows, providing farmers with supplementary revenue in order to face agricultural productivity decrease.

Why a focus on mixed crop-livestock systems?

To which extent are mixed crop-livestock systems resilient regarding climate change?

Mixed crop-livestock systems are still highly dependent to natural resources. Climate evolutions could accentuate temperature and precipitation high variability. Rainfall is likely to become more unpredictable, with generally shorter wet seasons and more frequent and intense heavy rains and cyclones. This implies greater variability of production and price volatility. Farmers perceive changes in start and end dates of rainy seasons, although clear direction of this evolution cannot be identified (NGO expert). Such evolutions may affect mixed farming systems in several ways. Floods may favor pests, diseases and weeds spreading. Cyclones may destroy crops and weaken animals. In addition, higher temperatures and CO_2 concentrations are expected to reduce the surface of savanna grassland.

However, mixed crop-livestock systems present certain resilience. Their nature implies a diversification of production and economic complementarity that increases peasant systems' flexibility to face climatic shocks. If one type of production fails because of unfavorable climatic conditions, other crop or animal production may compensate and ensure minimum food security.

Figure 18 - Mixed system in Togo **(AVSF, 2013)**

Mixed systems may therefore increase the capacity of peasants to face extreme events and ensure their maintenance (NGO expert).

Which representativeness of mixed crop-livestock systems?

As presented in the first part of the study, sub humid zones are characterized by the prevalence of savanna grasslands with pastoral societies and smallholder rain-fed cultivation, mainly for subsistence. Rainfall patterns generally allow breeders to grow crops. Rain-fed mixed crop-livestock farming therefore replaces livestock-only and crop-only systems when conditions allow it (agricultural land availability and access to market). Moreover, in areas with high population densities, land pressure forces farmers to associate crop and livestock production. Many families breed animals, even at very small scale. Livestock highly matters as a way of saving. In Togo for instance, almost all farmers have a least a small herd (NGO expert).

How are mixed crop-livestock systems agroecological?

Mixed crop-livestock systems present characteristics of agroecology. The integration of animal and crop productions allow for biological recycling: animal manure is used as organic fertilizer while crops and their byproducts feed animals. Besides restitution of organic manure, animals may strengthen the conservation of a dense multi-specific herbaceous cover close to natural vegetation. This dense cover allows for better interception of rain, slower mineralization of organic matter, increased fertilization and soil protection against erosion. Grazing also permits to avoid use of chemical herbicides which is frequent in some areas and increases soil exposure to erosion. Moreover, mixed crop-livestock systems are generally highly diversified, including associations of cereals and legumes and crop rotations (NGO expert). Moreover, livestock breeding can generate jobs (shepherds, blacksmiths…) and reinforce social integration between crop producers and breeders.

Which advantages of mixed crop-livestock systems?

Livestock both improves organic fertility and adds value to weak vegetation on poor soils which would otherwise be subject to deforestation. It represents an economic complementarity which is essential to secure regional farming systems. Also, dry cereal production is expected to be less affected by climate change impacts in sub humid regions than in sub-arid ones. Maintaining systems that associate crops and animals could permit to compensate for expected issues of livestock production that include reduction of grassland and land pressure. Moreover, breeders find solutions to face climatic evolution challenges and some global changes may produce opportunities for livestock farming. Population growth and new consumption patterns of emerging middle class stimulate demand for animal products (Vall et al., 2014).

Which limits to mixed crop-livestock systems?

Although mixed systems rely on agroecological principles and are highly diversified, they face some limits. In regions where land pressure is growing, surfaces cannot be left as fallow and soils are losing fertility. In addition, vegetable production sometimes relies on chemicals to control pests and diseases, as it is the case in many areas of Togo (NGO expert). Also in this country, many farmers are extremely dependent to mineral fertilizers and use them at high rates. Interactions between crop and livestock productions are not always fully exploited. Furthermore, livestock expansion and cultivated surface extension lead to an important stocking rate that weakens the environment and threatens natural vegetation (D’Aquino et al., 1995).

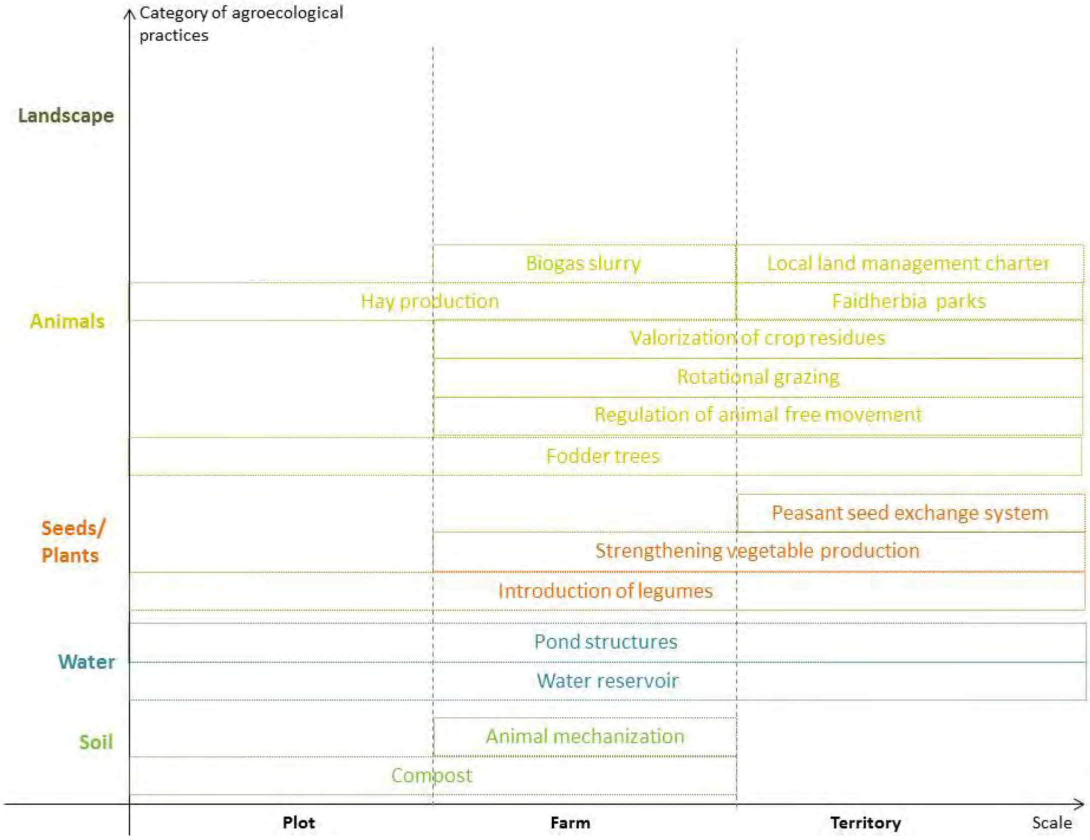


Figure 19 - Scale analysis of agroecological innovations in mixed crop-livestock systems

Which socio-economic factors threaten mixed crop-livestock systems?

Mixed crop-livestock systems are also threatened by socio-economic factors. Land insecurity, low investment capacity, and lack of outlet slow down production intensification. In West African sub humid zones, populations of local farmers and breeders coming from the Sahel with different cultures have coexisted for a long time. However, nowadays competitions for land and resources have become more serious and conflicts linked to land use are multiplying, reinforcing division between ethnic and religious groups. In addition, farmers also have to deal with competition for land from agribusiness projects which affect important zones in less marginalized lands with a good agricultural potential. In countries such as Madagascar, Soudan, Ethiopia and Ghana, between 1% and 2.5% of arable land are estimated to be concerned by agribusiness threat. Migrations linked to climate change also affect agricultural activities and dynamics in families. Farmers migrate to more fertile areas or to places where they will find non-agricultural activities. Women generally stay and take on all the work (Vall al., 2014).

In addition, insufficiency of public services and policies limit the development of livestock production. First, in many countries, zoo technical and veterinary services cannot meet the demand. Animal movements, reduction of animal health services, climate change and unmanaged urbanization complicate diseases control (Vall et al., 2014).

Table 4 presents the main challenges of climate change for peasants of sub humid Africa. Such evolutions imply great challenges for mixed crop-livestock systems. These challenges may be partly faced by a set of practices that have been mentioned in the interviews and in the literature and are summarized in Appendix 6.

These agroecological practices were then classified according to the scale they are implemented at, in **Figure 19**.

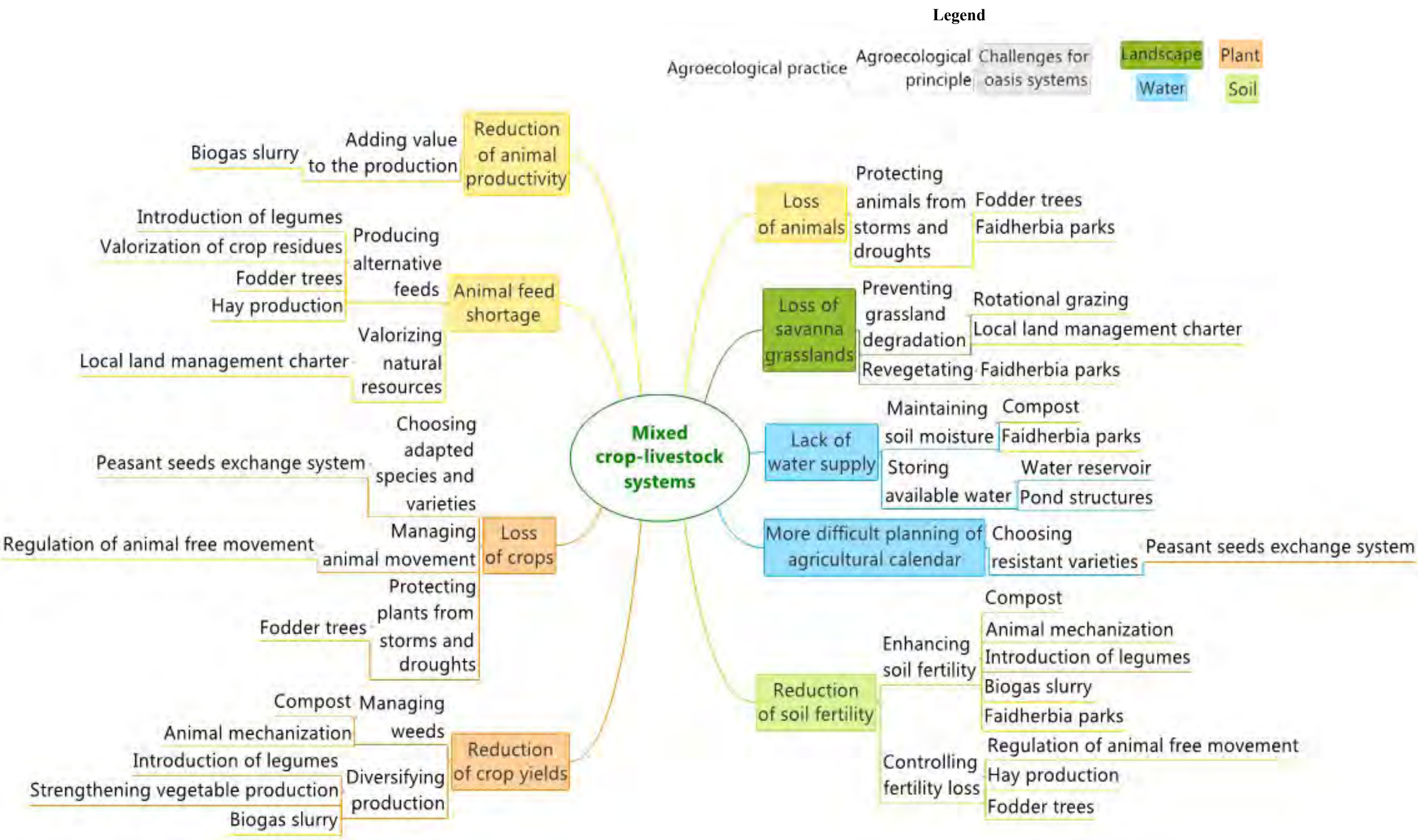


Figure 20 - Challenges to farmers with mixed systems and agroecological practices

Figure 19 shows that agroecological innovations in mixed systems have been inventoried at the three scales, although they seem to focus more on farm (41% of inventoried practices) and territorial scale (38%). Smallholders may focus on territorial and farm scale to manage the combination of animals grazing and crop cultivation.

Regarding the different agroecosystem's components, we can see that the majority of inventoried practices concern animal management (54%). This result may be biased by the tendency of interviewed people to talk more about animals than about crops. Peasants compensate for the loss of grassland surface and quality by organizing animals' displacement efficiently, in order to better take advantage of available resources; and by exploiting alternative feed sources. In addition, plant management improvement is addressed (20% of inventoried practices), with a strengthening of crop production. To a lower extent, some practices also focus on water management (13%) and soil fertility management (13%). Some farmers also organize collectively knowledge transfer.

Inventoried strategies of collective organization and production valorization

Another type of strategy implemented by peasants in sub humid areas which complete more technical ones concern knowledge transmission. In Senegal for instance, 20 groups of vegetable producers got involved in a program of **agroecological practices promotion.** Such programs facilitate exchange of knowledge between peasants. They also contribute to the organization of the sector concerned and a better valorization of farmers' productions. In Senegal, this program led to a rationalization of vegetable commercialization, allowing peasants to get higher revenue through a collective determination of higher prices for their products.

Figure 20 presents the link between identified challenges of climate change to mixed crop-livestock systems and inventoried agroecological practices. We can see that for each of the challenges posed by climate change to farmers with mixed systems, there is at least one agroecological practice inventoried responding to it.

Analysis of peasant strategies of adaptation to climate change

The inventoried agroecological innovations contribute to better take advantage of the interactions between crop and livestock productions and better manage natural resources to ensure sustainability of these systems. Peasants implement strategies to store available water (water reservoirs, pond structures, strengthening of vegetable production), to maintain soil moisture (compost, Faidherbia parks) and to adapt crop production through the choice of more resistant varieties (peasant seeds exchange system). These practices contribute to enhance the system's resilience to unexpected temporary droughts. Furthermore, smallholders may face grassland surface reduction by better managing soil fertility (compost, animal mechanization, introduction of legumes, Faidherbia parks, biogas slurry) and preventing erosion (regulation of animal free movement, rotational grazing, local land management charter, fodder trees, hay production). They may also compensate for the decline of forage availability by adding value to natural resources (local land management charter) and producing alternative feeds (introduction of legumes, hay production, fodder trees, valorization of crop residues). In addition, peasants aim at controlling crop and animal productivity decrease by protecting them from floods and cyclones' damages (fodder trees, Faidherbia parks) and controlling weed infestation (compost, animal mechanization). Finally, some peasants take parts in programs for knowledge transfer, which strengthen their farming systems and their collective work. The inventoried agroecological practices implemented by smallholders respond to the major challenges of climate change.

Farmers with mixed crop-livestock systems in sub humid Africa must face increasing variability of rainfall and appearance of temporary droughts. These factors are accompagnied by indirect effects of climate change: reduction of grassland surfaces, pests, weeds, diseases and parasites spreading. Some smallholders implement agroecological practices that contribute to respond to those challenges. They aim at maintaining soil humidity while choosing crop varieties that are more resistant to the lack of water. Furthermore, practices that favor soil fertility and protect it from erosion are implemented in order to limit soil fertility loss. To face the lack of forage, peasants valorize unexploited resources and produce alternative feeds. They also aim at controlling crop yields reduction through improved weed management and try to limit animal free movement on cultivated fields. Mixed crop-livestock sytems therefore present adaptation opportunities to climate change, based on agroecological principles.

2.2.6 Agroforestry systems of humid tropical regions

What characterizes an agroforestry system?

A diversity of agroforestry systems

The word "agroforestry" gathers "land-use systems in which woody perennials are deliberately used on the same land management unit as agricultural crops, animals or both, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components." (World Agroforestry Center in Marin, 2014). Agroforestry systems are characterized by plant associations' degree of complexity and spatial structure. In humid tropical zones, such systems result either from a progressive occupation of woodland by agriculture through the plantation of cultivated species under natural shade or from the plantation by humans of associations after complete clearing of wood or savanna plot.

Forest-based farming systems are generally based on shifting cultivation, but as population density increases fallow periods are progressively being reduced. Agroforestry constitutes an alternative to shifting cultivation. There exist a wide range of agroforestry systems: from relay cropping to complex multi-strata systems associating numerous perennial and annual plant species that mimic natural forests. In humid tropical Africa, agroforestry systems are peasant plantations combining perennial cash crops (coffee, cocoa, coconut…) with other plants such as trees for wood, fruit trees, subsistence crops, material for handicraft (palm, bamboo), medicinal plants and vegetative cover. Although livestock production is generally marginal in those systems, farmers may introduce animals in areas with high densities of population, where crop-only small farm predominance affects soil quality, and where foods lack. Livestock in humid areas is generally small, composed of small ruminants, pigs and poultry. In South Nigeria for instance, small ruminant breeding is spreading (D'Aquino et al., 1995).

How are agroforestry systems managed?

Peasants' agroforestry systems, for instance in Madagascar are based on rain-fed cultivation in small farms, with marginal livestock production. Subsistence trees and cash trees (litchi, clove, eucalyptus) cultivation is associated with rice, maize, cassava and legumes production. As shown in **Figure 21**, the different crops are distributed according to the topography: fruit and cash crop trees are cultivated at the top; fruit trees, root crops, cereals and legumes are grown on the slope; and vegetables and rice are produced in the plain (NGO expert).

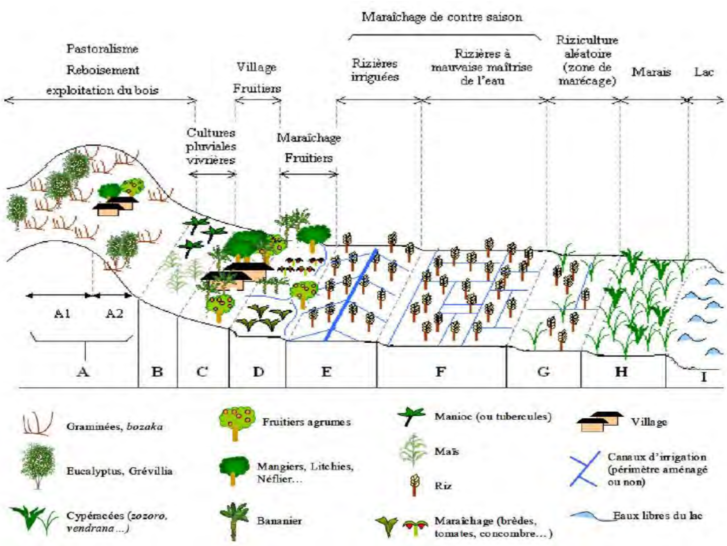


Figure 21 - Land use in the Alaotra Lake region

(Source: adapted from Rivera et al., The role of small-scale livestock farming in climate change and food security 2012, p.89)

Tree crop farming systems may also be considered as agroforestry as they are generally composed of tree crop production (cocoa, coffee, oil palm, rubber…) inter-planted with food crops (roots and tubers). Cassava, yam and cocoyam are the main staple while tree crops and off-farm activities are the main source of cash. Livestock keeping is limited by sanitary conditions although some systems include pigs and/or poultry.

In addition, different kinds of agroforestry techniques are implemented in all kinds of farming systems: hedgerows, grassy strips, cultivation under tree shade, reforestation. The same farmer may implement slash-and-burn techniques on some of his plots and agroforestry on others.

Why a focus on agroforestry systems?

To which extent are agroforestry systems resilient to climate change?

In the humid tropical zone, agroforestry systems are likely to be affected by several factors of climate change. The increase of mean annual temperatures and increased duration of heatwaves may provoke heat stress for crops. Such warming also leads to more frequent and intense heavy rains which are a factor of soil erosion and crop destruction. Increased moisture may favor diseases vectors that increase risks of contamination of crops and animals. These changing humidity conditions could also stimulate weed infestation. In addition, cyclones, which are becoming more frequent and intense, affect soils through wind erosion. There is therefore a risk of soil fertility loss. Cyclones also weaken animals when they are not protected by shelters, increasing their sensitivity to diseases. Furthermore, cropping calendar will be disturbed by changes in rainfall patterns: start and end dates of rainy seasons are increasingly unpredictable; rainy seasons are likely to become shorter while droughts duration extend and temporary drought become more frequent even during rainy season. Farmers will then have to face more unpredictable climatic conditions and adapt their planning strategies.

Agroforestry systems are quite resilient, including against cyclones (NGO expert). Indeed, their rich diversity strengthens their resilience. Risks linked to climatic and other extreme events are diversified, and so are income sources. For instance in Madagascar, if cyclone occurs in January, rice is affected whereas fruits are saved and the other way round. Furthermore, in most documented cases of successful agroforestry implementation, these systems prove to be more productive, more sustainable and more attuned to people's cultural or material needs than treeless systems (Mbow et al., 2014).
Which representativeness of agroforestry systems?

Agroforestry systems are not necessarily the most representative farming systems of the humid tropical zone, but they characterize these regions and are implemented by peasants. They significantly contribute to households' food security and have experienced recent increase in adoption by farmers in many parts of Africa (Mbow et al., 2014). Humid tropics have great species diversity and are suitable for complex agroforestry (Marin, 2014).

How are agroforestry systems agroecological?

Agroforestry systems are typically agroecological and therefore relevant to emphasize. Trees benefit to agroecosystems in several ways: they contribute to biodiversity regeneration; their roots in different soil strata allow for a better infiltration of water, reducing water erosion; they provide shelter for pollinator insects and birds; they limit evapotranspiration and thus water loss; they protect the soil against wind erosion (NGO expert) and erratic rains. Agroforestry takes advantage of interactions between species on a same plot: trees provide crops with shade allowing them to grow; legumes favor soil fertility that will benefit to other plants; plants have various rooting systems that explore different soil strata favoring its structure; animals may pass on fields and bring manure. Agroforestry also allows optimizing land use: some crops are able to grow on slopes whereas others valorize plains (NGO expert). Agroforestry improves natural resources use efficiency (space, soil nutrients, water, and light) and limits sanitary, climatic and economic risks thanks to products diversification (Penot and Feintrenie, 2014). Such systems favor a useful biodiversity with a market value while integrating a non-valorized biodiversity that plays an important ecological role.

Which advantages of agroforestry?

Agroforestry is increasingly recognized as a sustainable land use that contributes to farmers' ability to adapt to climate change. It enhances agro-ecosystem diversity and resilience while contributing to the limitation of greenhouse gas concentrations in the atmosphere (IPCC, 2014). In the humid tropical zone of Madagascar for instance, agroforestry systems often include a plant cover under fruit trees (coffee, banana, clove, pepper). Such systems favor plants recovering after extreme climatic events such as floods (Foubert, 2014). Agroforestry therefore provides multiple benefits: food provision, diversified income sources and environmental services. For instance, African peasants have been able to transform degraded agricultural landscapes into more productive and sustainable systems by integrating trees into annual cropping systems (IPCC, 2014). The vegetation cover may also contribute to a year-round cooling which could favor crop production (Christensen et al., 2007). Furthermore, agroforestry systems present several agronomic advantages. First, they maintain and even improve soil fertility, through the use of legumes, protection against erosion and reduced soil working (thanks to plant cover competition capacity). Plant covers may also constitute forage to feed animals. In addition, species diversity limits pests spreading. Land use optimization that characterizes agroforestry systems allows for increasing productivity per surface unit. Agroforestry can consequently be seen as a way to sustainably intensify farming practices for increased food security using socially and cost-effective management techniques. They require low external input, high recycling rates and sometimes crop-livestock integration.

Which limits to agroforestry systems?

Agroforestry systems have a high agricultural growth potential regarding resources and climate. However, this potential is limited in the short term because of small farm size, poor development of markets and isolation (FAO, 2001). In addition, as their land holdings are small, farmers are often unwilling or unable to dedicate land to agroforestry. Where land holdings are also insecure, farmers are often reluctant to invest in the long-term when it may benefit the next owner of their land rather than themselves (Mbow et al., 2014).

Also sometimes land owners do not permit peasants to plant trees because it is a sign of property. Moreover, agroforestry options are not applicable everywhere and the current stage of knowledge does not provide sufficient information on what systems work where, for whom and under what circumstances

Which socio-economic factors threaten agroforestry systems?

Agroforestry systems in humid tropical zones are subject to socio-economic stressors. Increasing population pressures natural resources. Furthermore, peasant systems generally cannot compete with monospecific conventional systems in terms of profitability of work and land in short and medium term (Penot and Feintrenie, 2014) and are thus threatened by their expansion. Nevertheless, in long term, agroforestry presents great advantages and characteristics of sustainability.

Agroecological innovations for adapting agroforestry systems to climate change

Table 5 presents the main challenges of climate change for peasants of humid tropical Africa. Such evolutions imply great challenges for agroforestry systems. These challenges may be partly faced by a set of practices that have been mentioned in the interviews and in the literature and are summarized in Appendix 7.

These agroecological practices were then classified according to the scale they are implemented at. **Figure 22** presents this classification.

Figure 22 shows that agroecological innovations in agroforestry systems have been inventoried at the three scales, although they seem to focus more on farm scale (45% of inventoried practices). Peasants work at farm scale to favor interactions between the different components of agroecosystems. Techniques implemented at plot scale are also well

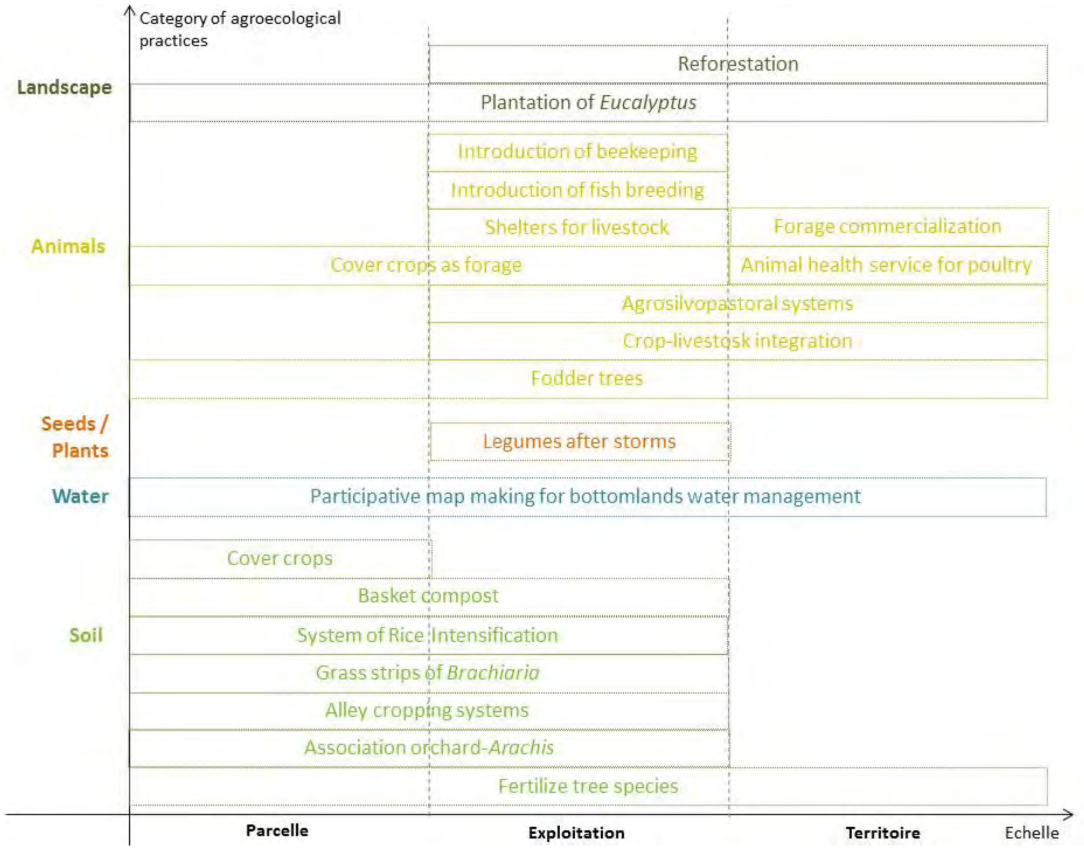


Figure 22 - Scale analysis of agroecological innovations in agroforestry systems

addressed (34%) and focus on favoring beneficial interactions between different plants.

Regarding the different agroecosystem's components, we can see that these innovations principally focus on animals (45%) and soil managing (35%). All inventoried practices tend to either manage fertility loss or diversify agricultural production. In addition, practices of landscape management are implemented (10%). Practices concerning plants and water (each 5%), are not emphasized here, but they are indirectly addressed through practices classified in "landscape" and "soil" components. Peasants seem to implement a systemic approach involving all components.

Inventoried strategies of collective organization and production valorization

To improve their resilience to climate change effects, one strategy of farmers is to better add value to their production, in order to ensure revenue that will strengthen their food security. For instance, in Madagascar, honey producers have gathered to create processing plants called **honey houses**. They are ensured to sell their production, which stimulates the amounts produced. This enhancement of honey production also contributes to improve local populations' diets thanks to honey's nutritional value.

Figure 23 presents the link between identified challenges of climate change to agroforestry systems and inventoried agroecological practices. We can see that for each of the challenges posed by climate change to farmers with agroforestry systems, there are plenty of agroecological practices inventoried responding to it.

Analysis of peasant strategies of adaptation to climate change

Les innovations agroécologiques recensées renforcent les systèmes agroforestiers. Pour The inventoried agroecological innovations contribute to strengthen agroforestry systems. To face

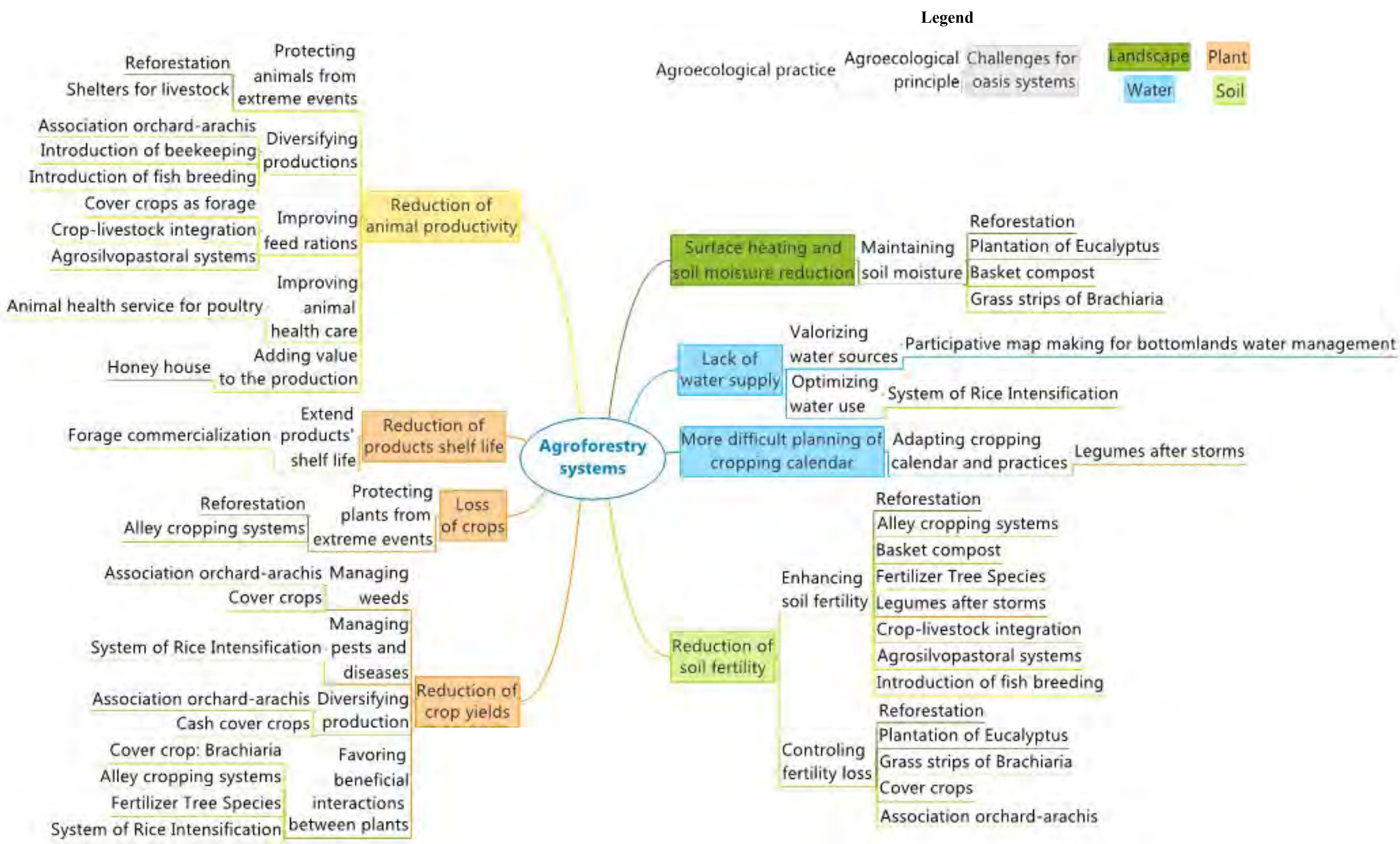


Figure 23 - Challenges to farmers with agroforestry systems and agroecological practices

water availability variability, peasants valorize water source (Participative map making for bottomlands water management) and optimize tbioheir use (System of Rice Intensification) while trying to maintain soil moisture (reforestation, plantation of Eucalyptus, basket compost, grass strips of Brachiaria). They also manage soil fertility loss through soil fertility stimulation (reforestation, alley cropping systems, basket compost, fertilizer tree species, introduction of legumes after storms, crop-livestock integration, agrosilvopastoral systems, introduction of fish breeding); and soil erosion control (reforestation, plantation of Eucalyptus, grass trips of Brachiaria, cash cover crops, Brachiara or Stylosanthes cover crop, association orchard-arachis, agrosilvopastoral systems, cover crops as forage). In addition, farmers face crop and animal productivity decline through different strategies. They manage weeds infestation (association orchard-arachis, cover crops) and pests and diseases spread (System of Rice Intensification). In addition, farmers protect crops and animals from extreme events' damages (reforestation, alley cropping systems, and shelters for livestock). Some focus on animals feeding and health (cover crops as forage, crop-livestock integration, agrosilvopastoral systems, and animal health service for poultry). Furthermore, a more global strategy to face climatic shocks is to diversify production in order to diversify the risks and ensure decent revenue (association orchard-arachis, cash cover crops, introduction of beekeeping, and introduction of fish breeding). Finally, smallholders may gather to add value to their productions (honey houses). Peasants' agroecological practices that have been inventoried in agroforestry systems of tropical humid Africa take all the agroecosystems' components into account (water, soil, plants, animals, landscape). Through production diversification and improvement of soil fertility and water managements, agroforestry systems present adaptation opportunities to climate change based on agroecological principles.

Peasants who implement agroforestry systems in humid tropical Africa have to face global warming and rainfall patterns evolution. Heavy rains and cyclones, which are more and more frequent and intense, threaten crops, animals and infrastructures. Some peasants implement agroecological practices that contribute to answer to those challenges. They face rainfall variability by better valorizing available water. Moreover, peasants protect the soil from extreme events thanks to plant covers, crop associations and trees that limit erosion. They also contribute to soil fertility with legumes and the introduction of restricted livestock. More generally, peasants diversify their farming systems, in order to limit the risks linked to climatic variability and ensure revenue. Agroforestry systems therefore present opportunities of adaptation to climate change based on agroecological principles.

We have seen that agroecological innovations are implemented in the four referent farming systems that respond to the main challenges arising from climate change. However, these practices may not be implemented specifically to respond to the effects of global warming. Indeed, farming is based on the constant adaptation to climatic variations. To respond to climate change consequences, farmers are used to implement this kind of practices. However, the impacts of climate change are going to be stronger, and peasants need more support to face them.

Peasants in oasis and agroforestry systems seem to work more at farm scale, to favor beneficial interactions between the agroecosystem's components. Agropastoral and mixed crop-livestock systems focus more on territorial scale, to manage access to grasslands and cultivation areas.

Nevertheless, there is not one practice that is more relevant than the other ones for adaptation to climate change. Agroecology does not provide universal solutions to respond to such challenges. Indeed, all agroecological practices are not applicable to all types of environments. However, associations of agroecological practices that complete each other can favor the functioning of each of the agroecosystems' components and their interactions. Such combinations may prove efficient to enhance the farming system's capacity to adapt to climatic evolutions and hazards in given conditions. There is therefore to consider a more systemic approach. That is why the following section presents some concrete examples of combinations of agroecological practices that respond to identified effects of climate change.

Part 3: Examples of combinations of agroecological practices to strengthen resilience of farming systems

3.1) Combination of agroecological practices in Mauritanian oases[8]

Figure 24 – Californian irrigation system
(Source : Tenmiya, 2011)

As presented in the previous chapter, oasis systems of arid regions have to face major challenges of water and soil fertility management which are accentuated by climate changes. In Mauritania, some peasants therefore work at plot scale in order to improve the management of both resources. In addition, they organize themselves into peasant groups to work collectively on oases' preservation and management improvement.

As presented in **Figure 25**, these peasants replace submersion irrigation systems by more efficient ones. They implement either **Californian irrigation systems** or **drip irrigation systems** (see description of both systems in Appendix 8). Both are supplied by submersible solar pumps. Californian systems present several advantages: they save water; they save time that can be dedicated to other activities; they can be used by women and children; they can be extended to neighbor oases; they imply new know-how for farmers (plumbing). However, they do not permit to maintain the microclimate effect that is provided by submersion systems and permits to have several vegetative strata. Drip irrigation systems allow for vegetable cultivation by women. This type of irrigation permits to increase water use efficiency while providing with significant yields.

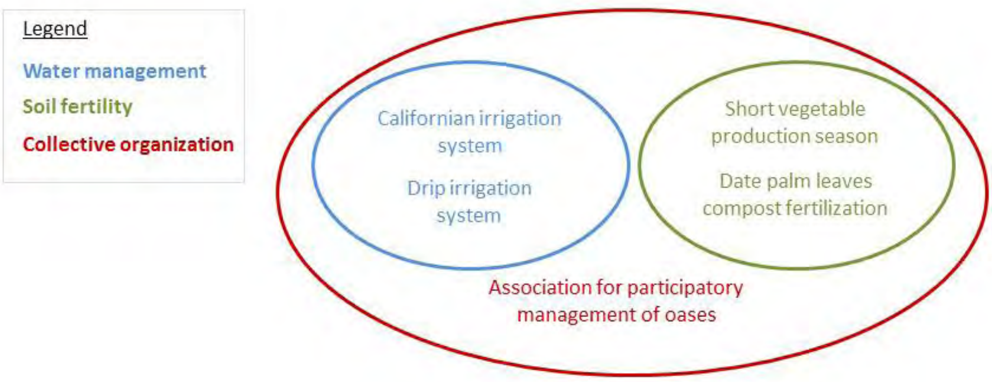


Figure 25 – Example of combination of agroecological practices in oasis systems in Mauritania

8 Result of interview with project coordinator of Tenmiya association

In parallel, the same peasants better manage soil fertility through **season cultivation:** they grow vegetable from October to December, then they plough the soil before spreading organic matter and letting the soil rest. This technique permits to prevent accelerated soil degradation and to maintain its fertility. Farmers use **compost from date palm leaves** as organic fertilizer.

At territorial scale, all oasis farmers of the area gather in a peasant organization which is called the **Association for Participatory Management of Oases.** This organization provides them with technical training and support. It is a place for peasants to exchange with each other, including during organized farm visits.

Peasants thus implement two complementary strategies: they gather in peasant organization to strengthen their professionalization; and they act directly by implementing efficient agricultural techniques. This combination of practices allows peasants to face water scarcity and soil degradation and therefore limits migrations of rural populations to cities.

3.2) 3.2)Combination of agroecological practices in Senegal[9]

In the sub-arid area of Niayes, Senegal, droughts combined with deforestation have led to serious land degradation that forces rural populations to migrate to cities. Agricultural production is based on rain-fed systems exploited during only three months of the year.

As presented in **Figure 26**, peasants implement agroecological techniques in order to manage water more efficiently and strengthen their systems' resilience to droughts. They **multiply the number of growth cycles within a year** by diversifying their production: to complement rain-fed production, these peasants introduced off-season vegetables, fruits and cereals. This diversification allows farmers to produce almost all year round and to diversify the risks linked to droughts. In parallel, the same peasants implemented **drip irrigation systems** which improve water use efficiency and permit to maintain cultivation off season.

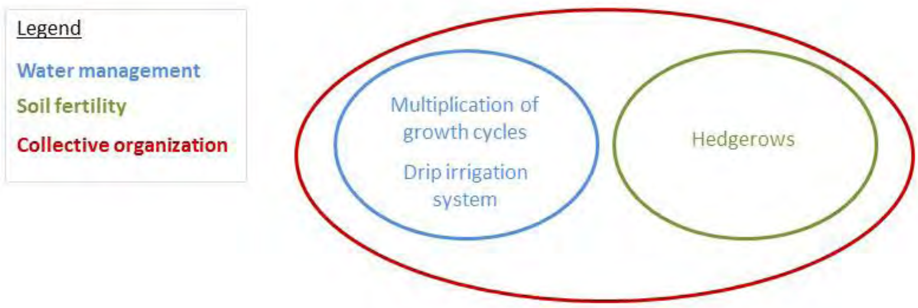


Figure 26 – Example of combination of agroecological practices in Senegal

In addition, these peasants limit soil degradation through the plantation of **hedgerows.** Leucenea specie is generally planted because of its fast growth that provides with fire wood. This technique presents several advantages: it limits wind and water erosion; it creates a protected environment for crop growth; it sequestrates carbon; it reduces evapotranspiration; and it provides with wood for energy.

Diversification of productions, including off-season crops, generates agricultural work in dry season that allow young people to remain in this area instead of migrating to cities. Land degradation caused by droughts and deforestation sometimes inhibit cultivation and constrain peasant to move to urban areas to find other activities generating revenue. Production diversification also contributes to improve local populations' diets. Also vegetable production introduction enhances women's economic power. Indeed, this activity is often practiced by women as it requires less hard work than for other types of productions.

9 Result of interview with program coordinator of ENDA Senegal

3.3) Combination of agroecological practices in Madagascar[10]

In sub-arid South Madagascar there is an important issue of soil fertility loss, because of heavy wind erosion, and partly because ploughing used to be implemented by farmers in areas where it was not suitable. Also agriculture relies on rain-fed systems which production is sometimes ruined by droughts or pests.

As presented in **Figure 27**, in order to adapt to these tough conditions, some peasants multiply **selected adapted local seeds.** These seed varieties (of species such as maize, sorghum or millet) which are first tested in research stations are then implemented in real conditions before being **multiplied by peasant groups.** These seed varieties are selected according to several criteria: they need to be perennial; to contribute to soil fertility restoration; to permanently cover the soil (maintain soil humidity); and to limit wind erosion. **Associations of crops** with these characteristics are then implemented. Although it takes time to select the seeds, it is worth it because results are ensured with adapted varieties. Part of this seed production is commercialized in **input shops** (100 in the whole region). In addition, these selected seeds are certified. As certification requires monoculture which is not adapted to local conditions and culture, they get an intermediary certification (Quality Declared Seeds) that gives farmers access to some markets.

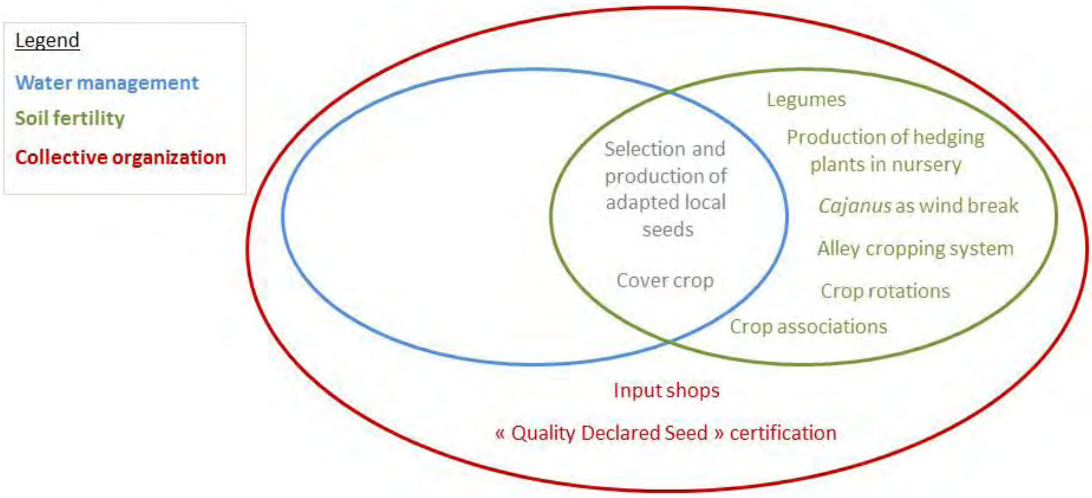


Figure 27 – Example of combination of agroecological practices in South Madagascar

To limit wind erosion, farmers also grow **hedging plants** in nurseries before planting them in their fields. Having them in nurseries makes them more resistant to droughts and winds than those directly sowed in the field. Also, the use of **Cajanus as wind break** is currently spreading by itself. It is planted around fields but also in **alley cropping systems** that include **crop rotations, legumes** and **vegetation cover.** Cajanus presents several advantages: it is perennial; its deep roots contribute to soil fertility restoration; and its grains are edible.

3.4) Combination of agroecological practices in Burkina Faso[11]

In Burkina Faso, in order to address the challenges of climate change regarding water and soil fertility management, peasants combine techniques to efficiently collect and use available water; and to enhance soil quality and prevent its degradation. This combination is presented in **Figure 28**.

Regarding water management, peasants implement strategies at two scales. At family scale, they collect rainwater through their **roofs** and **catchment areas.** At community scale, farmers install **water reservoirs** and **mini dams** to collect run-off water and **wells** for

10 Result of interview with project coordinator of Gret Madagascar
11 Result of interview with director of ARFA and expert of AVSF

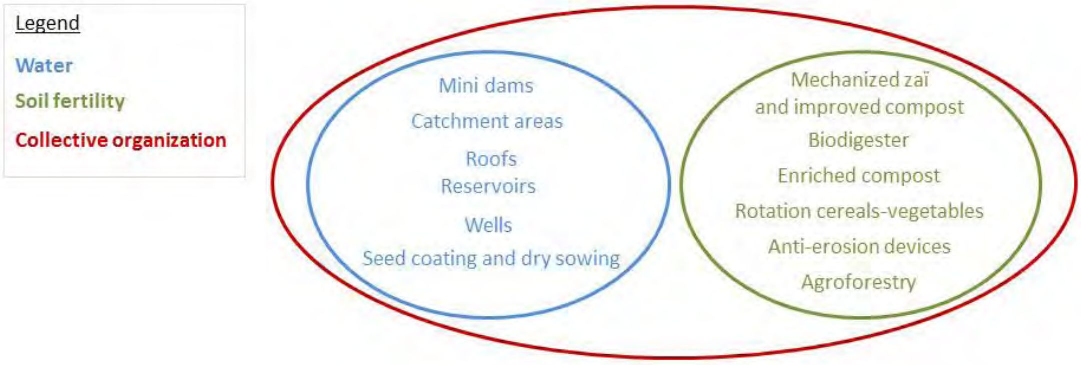


Figure 28 – Example of combination of agroecological practices in Burkina Faso

groundwater. In addition, farmers implement techniques during sowing phase to reduce the risk arising from droughts. They practice **seed coating** that constitutes a humid layer, (with clay soil, compost and cereal bran) and sow those seeds in zaï holesv (see description of technique in Appendix 8) before rain comes. This technique permits to reduce the risks linked to dry sowing; suppress the need of pre-germination; avoid consumption of seeds by ants, termites and birds because they cannot recognize them anymore; and gain two days on evapotranspiration.

In parallel, peasants improve soil fertility through several techniques. First, they improve zaï holes with addition of **improved compost** (instead of household waste) and digging mechanization. However, this technique may be limited by water scarcity for compost in dry season, and the additional work to prevent composting material from being destructed by animals. To respond to the lack of water, a group of women started exploiting a well and became producers of improved compost. The combination of **mechanized zaï holes** and improved compost improved working conditions of peasants while restoring degraded lands. Thanks to this technique, peasants are not forced anymore to move to more fertile lands. Secondly, a new technique has been recently tested by farmers, which is **enriched compost.** Compost can be enriched either with trichoderma, which acts as a fungicide and liberates phosphorus, or with natural phosphate. Thirdly, some peasants produce another type of organic fertilizer produced by a **bio digester.** This technique uses animal excrements to produce biogas which provide families with energy. The bio digester also produces effluent which is then composted and used as fertilizer to produce forage that will be consumed by the animals. These farmers also consider using water catchments to supply the bio digester with water. This technique therefore takes advantages of the interactions between livestock breeding, crop production and water management. In parallel, farmers also prevent soil degradation with two types of strategies. They implement **anti-erosion devices** such as stone bunds and contour bunding in order to maintain organic matter (compost) on plots and soil humidity. They also practice **agroforestry**: they plant cereals in Acacia parks. Acacias enhance soil fertility thanks to fruits that fall on the floor, and protect soil from erosion. However, these trees do not provide with a lot of shade for cereal growth. Finally, those peasants practice **rotations of cereals and vegetables.** Thanks to the water contained in wells and midi dams, farmers can produce vegetables from October to April, before sowing cereals in wet season that will benefit from vegetable fertilization. This successful system demonstrates that it is possible to grow vegetables with no use of chemical inputs.

3.5) Combination of agroecological practices in the plateaux region, Togo[12]

In the plateaux sub humid region of Togo, peasants combine several strategies to restore and maintain soil fertility, which are presented in Figure 30. They traditionally manage soil fertility by including a period of **fallow** in their farming systems, although its duration is increasingly limited by population growth pressure. In addition, **soil-improving plants** are planted to enhance soil fertility. For instance **Cajanus cajan**, which is a legume shrub, is planted in fallows and sometimes around plots. Besides its fertilization capacity, this

12 Information extracted from De Witte, 2013.

plant presents other advantages: its grains are consumed by local populations and its stems provide fire wood. In parallel, peasants favor **agroforestry** systems. Cash trees are planted (such as cashew tree, oil palm or teak), and crops cultivated under them. Furthermore, **some tree species are preserved** (baobabs, papaya, shea, mango trees… etc.). They provide with fruits for local populations' alimentation; their wood is used for energy and constructions; they bring shade for workers; and some of these trees' leaves constitute green manure (Neem, Leucaena).

Figure 29 - Cajanus Cajan, Togo

(Source : De Witte, 2013)

In this region of Togo, peasants therefore adopt strategies of diversification and plant-based improvement of soil fertility to maintain their production capacity. By maintaining tree species that provide with foods and enhance soil fertility, peasants contribute to food security of local populations and to the maintenance of fertile land in long term. Such plant associations may also contribute to improve their resistance to the spreading of weeds, pests and diseases.

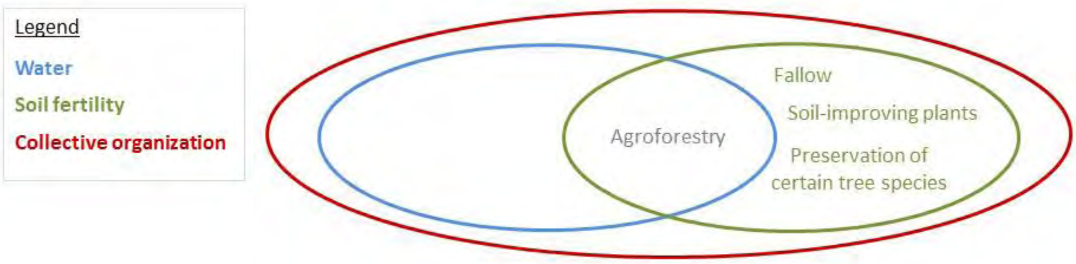


Figure 30 – Example of combination of agroecological practices in Togo

3.6) Combination of agroecological practices implemented by the Sénoufos in North Cote d'Ivoire[13]

In sub humid North Cote d'Ivoire, peasants have implemented agroecological practices for centuries. These techniques, presented in Figure 31, allow them to adapt rain-fed production to rainfall variability and to preserve soil fertility. They implement **itinerant farming systems** (cultivation is rarely practiced more than 3 consecutive years on the same plot) which are based on a **high diversity of cultivated crops.** They **associate subsistence crops** with different growth cycles on the same plots (tubers, cereals, vegetables…etc.). Vegetables (such as eggplant or chili) are sown in yam fields. In addition, Sénoufos implement **crop rotations** which compositions are adapted according to the presence or not of rainfall (crops more or less water demanding). After yam, peasants generally cultivate cassava or peanut. Then, **fallow** is practiced during 2 to 3 years for the soil to rest. Furthermore, a complementary strategy of these peasants is to adapt cropping calendar: they **modify sowing date** for crop growth to occur in most favorable period of the year. In addition, farmers adopt **shorter-term varieties** (of rice for instance) which are more adapted to rainfall variability than long-term ones. Moreover, Sénoufos also acknowledge the role of woods in climate regulation and cooling, and therefore aim at **maintaining forests**.

This diversified production provides populations with foods and significant income and permit to diversify the risk linked to climate. Sénoufos' farming systems are a great example of

13 Information extracted from Cherif, 2014

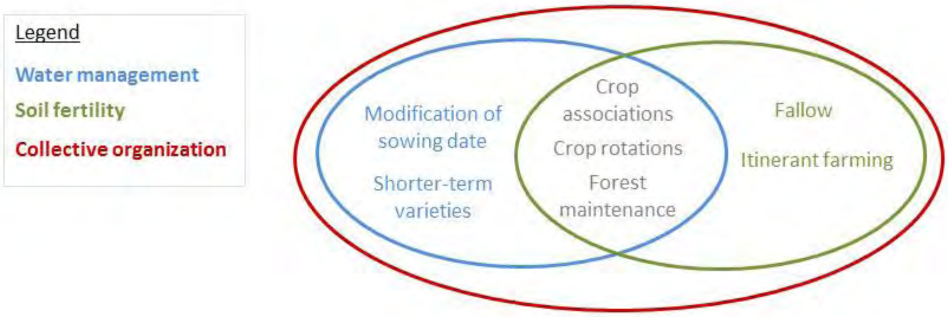


Figure 31 – Example of combination of agroecological practices in Cote d'Ivoire

adaptation to climate variability based on agroecological practices.

3.7) Combination of agroecological practices in Bamileke country, West Cameron[14]

In humid Bamileke country, West Cameron, some peasants have developed combinations of agroecological practices, which are summarized in Figure 33. They cultivate in highly diversified subsistence farming systems based on tubers. Sufficient rainfall in this area allows farmers to cultivate cassava and yam, in **association with many species and varieties of crops.**

Figure 32 – Example of crop association in Bamiléké country, West Cameron

(Source : Valentin Beauval)

These peasants associate **fruit trees** (such as avocado) with 3 to 4 intermediary crops (banana, coffee). Under these trees and shrubs, we can find 10 types of **annual crops** that are cultivated depending on soil types. Maize, beans, groundnut and/or leafy vegetables are association with tubers (yam, taro and macabo), and crops such as soybean. In addition, **hedges** are planted around the fields which provide with wood for construction. Such associations permit to greatly optimize the use of surfaces, while enhancing crop yield thanks to beneficial interactions between plants.

These systems include very little livestock production (some black pigs and small ruminants), because of the presence of Tripanosomia that limits cattle breeding. They therefore rely on **legumes** and trees for organic fertilization. Large **soil cover** also limits soil erosion.

Such diversified systems present great potential to face the major challenges arising from climate change in tropical areas. They permit to maintain soil humidity. They limit soil erosion while enhancing its fertility. Furthermore, annual crops may be protected to a certain extent from extreme climatic events, such as heavy rains and cyclones, by surrounding trees. Also crop associations are supposed to have better management of pests and diseases than monoculture systems. However, such systems present a low productivity of work.

14 Result of interview with associated expert of AVSF

Combinations of agroecological practices are implemented in various regions of Africa to strengthen farming systems' resilience to global changes. Peasants combine agroecological techniques to better manage the different agroecosystems' components and favor their interactions. These improvements contribute to improving living conditions of rural populations and increasing food security. Peasants' strategies should therefore limit migration of populations to urban areas.

These combinations of practices proved successful in the studied cases. But are they applicable to other peasant systems in other regions of Africa? What are the conditions of success of agricultural innovations? What are the costs of implementation of such practices, also in terms of workforce?

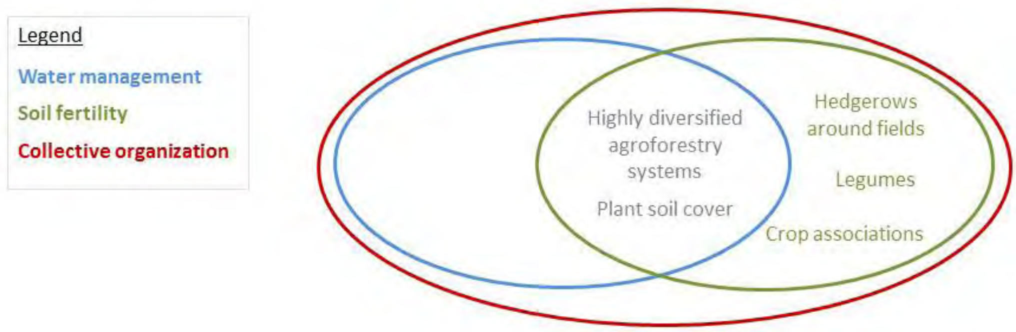


Figure 33– Exemple de combinaison de pratiques agroécologiques à l'Ouest du Cameroun

3.8) Key factors of the adoption of practices by peasants

One should consider several factors when implementing adaptive strategies to climate change. Multidisciplinary approaches should therefore prevail (LOCEAN et al., 2015). First, agricultural innovation requires identification and understanding of existing practices of target populations which have often developed great knowledge on adaptation to adverse environments and climatic shocks. Traditional and scientific knowledge should be combined through participatory approaches for an improvement of existing farming systems' management. Adaptation strategies have a better chance to be adopted and prove successful when based on indigenous knowledge. Secondly, the issue of social acceptance and appropriation of technical innovation must be addressed. Local leaders who test and promote successful innovations could contribute to this acceptance and appropriation. Furthermore, social and cultural factors may stimulate or limit innovation. Vulnerability and adaptation capacity of Human communities are linked to the composition of livelihoods, the role of social safety nets and other social protection measures (mutual assistance, microcredit…). Also, transformational adaptation sometimes relies on higher investment or shift in fundamental values and expectations which may create greater resistance among farmers (IPCC, 2014). Thirdly, there is to acknowledge political and economic factors which influence peasants' decision to adjust their practices. Indeed, effective functioning of institutions and governance systems play a major role in adaptation. Also, peasants' access to markets and infrastructures must support adoption of innovations. Adaptation capacity may be limited by complex factors such as extreme poverty and limited technical knowledge and resources. Some practices require significant investment (equipment, workforce, seeds purchase…) which are more than peasants can afford. Peasants may not be ready to take the risk of shifting to new practices whose results are uncertain in the short term. Finally, the question of transferability of innovation from one agricultural production scheme to another one should be considered, taking into consideration biophysical factors and the other factors underlined above. Considering the diversity of factors influencing the implementation of adaptive processes, there is to recognize that no single adaptation strategy exists, but that there are as many strategies as specific contexts in Africa.

Conclusion

General conclusions on climate change trends over Africa are difficult to draw as climate and its effects are very variable depending on location, even inside climatic zones. However, it can be said that mean temperatures are rising over the whole continent. Rainfall patterns variability increases as well, although it has different results depending on the regions. Annual amount of rainfall declines in some areas whereas it increases in others with a concentration in shorter time periods. We can generally say that wet seasons shorten. In addition, extreme climate events' frequency and intensity are augmenting. Their nature varies according to location (droughts, heat waves, heavy rains, floods, cyclones…).

The different climate trends are likely to affect farming systems of arid, sub-arid, sub humid and humid tropical Africa, and especially peasant ones which are more vulnerable because they strongly depend on climate (rain-fed systems, grazing animals). Peasants therefore need to anticipate, as they often live near the margin of subsistence, in order to be able to survive and ensure food security for their families. Major threats arising from climate change to agriculture in Africa have been identified. First, natural resources availability (water, pasture…) is likely to be negatively impacted by rainfall patterns evolution. Secondly, soil fertility loss will be accelerated by higher temperatures and extreme climatic event multiplication, provoking a loss of arable land. Thirdly, crop yields and animal productivity will most likely be restricted by heat and water stress, nutrient shortage, extreme events and pests and diseases development. These restrictions of agricultural activity might cause more and more migrations of rural populations to less impacted and urban areas. Yet, African peasants have always had to deal with climate variability. They have developed great knowledge and practices in response. This knowledge needs to be transferred to new generations, and combined with scientific one to strengthen existing farming systems.

African peasants have implemented agroecological practices for a long time to manage the different components of their farming systems and take advantage of their interactions. These practices can generally also respond to the major threats of climate change, as they are based on more efficient use of natural resources. As extreme climatic events indirectly affect the soil, peasants have introduced or developed existing techniques to prevent land degradation, such as anti-erosion devices. Furthermore, in order to limit soil fertility decreses, peasants generally bring different forms of organic fertilizer and maintain plant covers. To face water availability increasing unpredictability, peasants implement techniques to efficiently use water and maintain soil humidity. More globally, peasants generally manage risk through diversification. They diversify their production by introducing new plant species and varieties (in association on the same plot or not), and/or by introducing animals into their farming systems. This strategy permits to diversify both climate risk and income sources. Another major threat which has been identified in the study is the development of pests and diseases vectors, which is favored by novel climatic conditions. Yet, few practices are implemented to manage this risk. When feasible, it may be relevant for peasants to try to develop knowledge in biological control which relies on the use of natural enemies.

Nevertheless, this study permitted to evaluate the potential of agroecology for adaptation of African peasant farming systems to climate change. As we have seen, the agroecological approach takes into consideration all the components of the agroecosystem, in order to strengthen its functioning and therefore its resilience. Agroecology relies on a holistic approach which has been presented through the examples of combinations of agroecological practices. Many experiences of implementation of agroecology in various African regions have proved successful and allowed for improving farming systems' resilience and food security of local communities. These combinations of practices permit to address the challenges affecting each of the agroecosystem's components, at plot, farm and territory scales.

To strengthen agricultural techniques and increase their capacity to face climate change effects, peasants also improve their collective organization. They gather to better add value to their production (transformation, direct sell, labelling); to professionalize their production sectors; to share equipment; and to exchange knowledge with each other's. Several examples of collective organization have been mentioned in the study (peasant organizations, cooperatives, processing plants, certification, short food supply chains… etc.). These organizational innovations improve farmers' access to markets, which is a major condition of their survival against unfair industrial farms competition and of local food security. Short food supply chains benefit to both local producers and consumers. Several interviewed people emphasized the need for farmers to share knowledge. This sharing is promoted through participatory action systems such as Farmer Field Schools where peasant can take part in training sessions on agroecological techniques; or multi-actor research platforms which take peasants' expectations into account.

This study demonstrates the potential of agroecology for adaptation to climate change. Although beneficial effects of agroecological practices may not be felt in short-term, their potential is huge in longer-term perspective. Other approaches, such as biotechnologies (GMOs…) may permit yield increase and punctual adaptation to new contexts, but agroecology secures the sustainability of peasant systems by strengthening the complete system. Agroecology therefore appears as a concrete solution to strengthen farming systems and ensure their maintenance for food security improvement. African peasants may be the most vulnerable to climate change effects, but they could also have the greatest chance to adapt, thanks to their rich traditional knowledge of agriculture adaptation to biophysical conditions.

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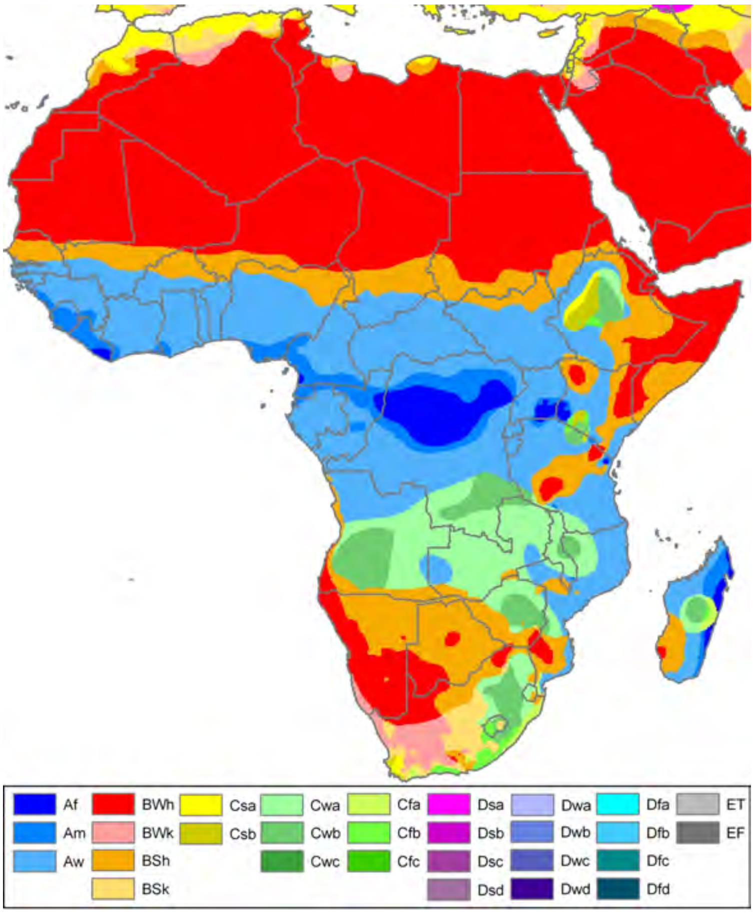
List of appendices

Appendices

Appendix 1: Köppen-Geiger climate type map of Africa



Köppen-Geiger climate type map of Africa
(Peel, M. C. et al., University of Melbourne, 2007)

Appendix 2: Questionnaire on agroecological innovations

1. Identification of person interviewed

- Organization
- Functions

2. First part of the study

Objective: define on which zones the person can provide with information; discuss results of Part 1

- Show map of the different zones: On which zones does he/she work?
- Part 1: presentation of the main results of literature review on climate changes and their impacts. What does he/she think of these results? What has he/she observed in their intervention zones?

3. Second part of the study

o The referent systems

Objective: explain why we focus on referent systems; discuss the relevance of chosen referent systems; get information to characterize the referent systems

- Choice of referent systems: 2 criteria: representativeness and reliance of agroecological principles
- Relevance of these systems? Why?
- How to characterize these systems? Does he/she have references on the systems?
- What are agroecological principles according to him/her?
- Why can we say that these systems rely on agroecological principles?

oAgroecological innovations to face climate change

Objective: precise the subject (definition of scales); relevance of referent systems regarding climate change adaptation; get detailed information on the systems for each of the 3 scales (plot, farm, territory); identify combination of agroecological practices

- Precisions on the subject: presentation of the different scales
- The systems' resilience to climate change? In the past 50 years, has a major extreme climatic event affected the system? How did it react?
- How can the systems be innovative? Does he/she have observed innovative agroecological practices in these systems? At plot scale? At farm scale? At territorial scale?
- One detailed practice per scale: description, advantages and limits, innovative aspect regarding climate change, relevance, and reliance on which agroecological principles?
- Does he/she have information on other agroecological practices implemented to face climate change in the systems? And in general in the zone?
- Combination of practices: does he/she know combination of agroecological practices that permit to increase the systems' resilience to climate change?
- Where would he/she say that innovations mainly come from? (endogenous, exogenous)
- Does he/she have literature to provide me with? Scientific papers, diagnosis, project capitalizations, master thesis (in French or English)

4. Other relevant people to interview?

Appendix 3: Questionnaire on combinations of agroecological practices

1. 1. Identification of person interviewed

- Organization
- Functions

2. Presentation of the study

- The different zones of study
- Part 1 : characterization of climate changes and their consequences for agriculture
- Part 2 : identification of referent systems ; inventory of agroecological practices
- Part 3 : identification of combinations of agroecological practices

3. Combinations of agroecological practices

No practices are more relevant than others to face climate change, but there exist associations of practices: per scale and cross-scales (plot, farm, territory), that contribute to enhance peasant systems' resilience to climate change.

According to the zone you know:

- Could you give me an example of combination of agroecological practices that are often observed in peasant systems (in the referent systems, or in the climatic zone)

To face major climate changes:
- Arid zone: reduction of water supply ; loss of soil fertility
- Sub-arid zone : uncertainty about water availability in time and space ; lack of forage for animals
- Sub humid zone: temporary droughts ; loss of pastures ; spreading of weeds, pests and diseases
- Humid tropical zone : uncertainty about water availability in time and space ; loss of soil fertility; destruction of crops by extreme events

- Could you give me an example of combination of agroecological practices which is very complex and specific?

- Do you know where these combinations come from? (endogenous/exogenous)

- Do you have literature on these combinations?

Appendix 4: Agroecological innovations inventoried in arid regions of Africa

All the agroecological practices mentioned for the arid zone are presented here. You can see which ones have been mentioned specifically for oasis systems (column "Referent system"). Practices are classified depending on the components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow), collective organization (red).

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Bench terracing		Reduced soil erosion; Increased crop production; Safe cropping operations on slopes	Only on slopes steeper than 15% and where soil conditions are favorable	Traditional technique in Africa		Baker 2015 (CARE)
Reforestation		Carbon sequestration; Diversification of productions; Maintenance of soil fertility				Terre et humanisme 2014
Californian irrigation system	Oasis	Reduction of water loss on sandy soil; Water transport to remote plots				TENMIYA 2011
Drip irrigation system	Oasis	Irrigation efficiency; Reduced loss of nutrients				CARI
Solar pumping system	Oasis	Higher quantity of available water; Diversification of productions; Time and money saving; Relatively low environmental impact	High cost of installation	Morocco (CARI)	Mali (AVSF)	CARI 2014
Collective irrigation management	Oasis	Irrigation efficiency; Reduced water loss; Water storage in anticipation of dry periods; Increased productivity; Strengthening of collective spirit	Agreement required between water users		Adoption facilitated by farmers' motivation and public funding for oasis protection.	RAC 2013
Jessour irrigation system		Water saving; No specific equipment required; Diversification of production; Higher yields; Higher income; Higher water infiltration; Reduced water erosion; Creation of arable surfaces; Filling of groundwater table; Biodiversity restoration	Not implementable if more than 250 mm rain per year; Hard maintenance; Reduced pastureland; Reduced runoff water quantity available for downstream users	Traditional technique of arid zones, largely used in Tunisia		Interview CARI
Borders		Enhanced water infiltration for crops		Tanzania		Baker 2015
Sump		Water availability for small herds in dry season; Availability of grazing areas after wet season; Enhanced food security thanks to herd and income maintenance; Distribution of water spot and grazing areas; Based on local knowledge of soils; Low cost	Hard work; Specific knowledge for digging; Low water flow; Pollution of groundwater table by animals	Traditional technique of transhumant populations such as Touaregs and Peuhls.		Technical sheet of GTD
Water source networking		Ensure herds displacement with minimum loss; Better knowledge of water spots and pasture				Cornu 2011; interview AVSF
Date palm compost	Oasis	Soil fertilization; Valorization of local biomass	Slow decomposition of date leaves	Tunisian association		CARI 2014
Manure compost	Oasis	Soil fertilization with elaborated product ; Limitation of weed infestation	Restricted availability of manure			Interview CARI
Date palm mulch	Oasis	Soil cover; Protection against erosion; Soil humidity increase		Morocco (CARI)		CARI 2014
Association wheat-alfalfa	Oasis	Optimization of cultivated surfaces; Enhanced soil fertility; Diversification of productions		Some farmers in Maghreb	Has not spread so far.	Interview CARI

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Intercropping	Oasis	Pests and pathogens control; Protection against erosion; Attraction of beneficial insects; Better weed control; Land use optimization; Diversification of productions	Risk of yield reduction if crops have different competitive abilities	Tanzania (CARE)		Baker 2015
Crop rotation	Oasis	Preserved and enhanced soil fertility; Improvement of soil structure; Pests and pathogens control	Selective crops may give lower yields	Traditional technique in Africa		Interview ACF
Compost		Diversification of soil fertilization modes; Limitation of weed infestation; Higher soil humidity			Reduced weed infestation; improved soil structure	CARI
Minimum tillage		Time and energy saving; Increased yields; Crop residues as forage; Higher income; Limited soil degradation by wind and water; Reduced soil compaction; Organic matter accumulation; Lower evaporation; Enhanced water infiltration	Need of mechanical or animal workforce; High cost of animals and equipment maintenance; Higher risk of weed infestation	Traditional African farming practice, developed in Sub-Saharan Africa in the 1980's	Adoption is sometimes limited by equipment cost, work hardness, high weed pressure	Technical sheet of GTD
Double digging		Increased soil drainage; Increased soil aeration: facilitated root penetration	Hard and time-consuming work; May disturb soil life	Tanzania		Baker 2015 (CARE)
Nursery on hot layer and early sowing	Oasis	Larger production; Higher incomes (better prices on markets when selling some weeks earlier)		Morocco (CARI)		CARI 2014
Nectar-producing plants planting	Oasis	Favoring pollinators; Enhanced biodiversity		Morocco (CARI)		CARI 2014
Introduction of vegetable production		Diversification of productions and income; Ensure production in unfavorable years; Production in dry periods; Higher quality of families' diet				Terre et humanisme 2014;Sokpoh 2014 (URD) ; interview AVSF
Introduction of spineless cactus production		Forage source for animals	Low nutritional value			INRA 2014
Rotational grazing		Avoid overgrazing; Maintain pastureland in long term; Low workforce required; Organic fertilization; Increased forage quantity and quality; Increased animal productivity; Higher income; Higher soil humidity; Lower runoff (plant cover); Enhanced plant biodiversity	Global farm planning required; Expensive equipment (fences or surveillance); If not well managed: spreading of less palatable plants	Implemented by breeders in sub humid zones. Diffusion from external development actors		Technical sheet of GTD
Organization of grazing paths		More efficient management of pastures; Organic fertilization of fields; Grass maintenance	Conflicts between crop and livestock producers			INRA 2014; interview CCFD
Training in agroecological practices		Diffusion of agroecological practices; Higher acceptability thanks to demonstration		Association PROMMATA		CARI; PROMMATA 2014
Construction of cooperatives	Oasis	Better valorization of production				CARI
Processing plants	Oasis	Better valorization of production; Longer duration of products storage				CARI
Short food supply chains	Oasis	Better valorization of production; Closer relation with consumers				CARI; interview CCFD
Fairs	Oasis	Better valorization of production; Closer relation with consumers				CARI

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Production of organic henna	Oasis	Diversification of production; Valorization of production		Morocco		CARI
Labelling Demeter dates	Oasis	Better valorization of production		Tunisia		Interview CARI
Dairies		Better valorization of production		Senegal, Mauritania, Niger, Mali		INRA 2014
Organization of meat sector		Better valorization of production				Interview CCFD

Appendix 5: Agroecological innovations inventoried in sub-arid regions of Africa

All the agroecological practices mentioned for the sub-arid zone are presented here. You can see which ones have been mentioned specifically for agropastoral systems (column "Referent system"). Practices are organized depending on the components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow), collective organization (red).

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Wind breaks (Cajanus cajan)	Agro pastoral	Limitation of wind erosion		Madagascar (AVSF)		Interview AVSF
Grass strips		Enhanced biodiversity; Soil protection against wind and water erosion; Lower surface temperature; Forage production; Additional income; Additional use of hay (fence, roof, handicraft); Easy implementation; Low equipment requirement; Low investment (available plants and seeds); Increased soil humidity	Required surveillance against animals during first year; Required soil work before implementation; Reduction of cultivated surface (compensated by higher yields); May attract pest	Implementation with stone bunds to stabilize them	Better valorization of rain water and water retention. Increased yields if associated with organic fertilization. Traps mineral-rich sediments and organic matter transported by water.	Dorlöchter 2012; Technical sheet of GTD
Assisted Natural Regeneration		Limited water erosion; Enhanced vegetation; Protection against soil degradation; Soil fertilization; Low cost; Additional income from non woody products	Land insecurity; Required surveillance at the beginning in dry season to protect plants from animals			Dorlöchter 2012; interview Salvaterra
Reforestation		Reduction of wind erosion; Restoration of non-arable land		Senegal: ENDA, villages, local associations	Improve water quality; Filling of groundwater table; Women involvement	Berton 2013
Re-vegetation		Soil cover; nitrogen enrichment of the soil (natural compost); higher local food availability; higher yields; water retention; reduced water losses; lower surface temperature; revenue source diversification; lower vulnerability to climatic and economic variability; C			In Niger: 12 million hectares re-vegetalized, with higher groundwater sources level; improved food security. Increasing number of farmers implementing this technique.	RAC 2013; Aune 2011; interview GRET
Agroforestry		Enhanced biodiversity; protection against erosion; Better water infiltration; Pollinators shelter; Lower surface temperature; Lower evaporation				Interview ACF

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Plantation of legume trees		Soil protection against erosion; enhanced soil fertility; improved local populations' diets		Madagascar: legume trees as Cajanus cajan and cover crops like mucuna and konobe	Soil fertility improved within 3 years. Cajanus cajan: food for local population, improving their food security and living conditions.	Lheriteau et al. 2014
Acacia albida hedgerows		Protection against wind erosion; crops protection; humidity maintenance; lower surface temperature; higher revenues; production of fodder, fruits and wood				Aune 2011; interview GRET
Plantation of Acacia tumida		Large quantities of fertilizer produced; resistance to droughts; edible seeds and for poultry feeding; protection against wind erosion	Requires more than 300 mm of rain per year			Aune 2011
Plantation of Moringa		Nutritional value of leaves abundance in wet and dry seasons; low labor; market for leaves and flowers	Animals may consume them	Popular tree in Niger and North Nigeria (René's idea)		Aune 2011; interview AVSF
Bench terracing		Reduced soil erosion; Increased crop production; Safe cropping operations on slopes	Only on slopes steeper than 15% and where soil conditions are favorable.	Tanzania: traditional technique		(Mwanyoka 2015 CARE)
Mechanical dune fixing		Easy implementation; Low maintenance required; Low cost if available branches; Increased income in the long term; Diminution of wind speed; Reduction of erosion; Protection of natural ponds	Work demanding in the first years; Competition for resources in case of limited wood and forage availability; Higher temperature in protected zone; High cost at large scale	Senegal in the 1970's and Mauritania in the 2000's	This technique limits wind speed and wind erosion; protects arable land from sand; immobilizes sediments transported by the wind	Technical sheet of GTD
Biological dune fixing		Easy implementation; Low maintenance required in long term; Production of wood and forage; Production of compost and mulch; Increased income; Increased biomass; Limited wind speed; Limited erosion; Higher soil fertility	Knowledge required; Important maintenance work in the first years; Required access to seeds and/or nursery; High cost of plants produced in nursery; High water demand; High cost at large scale	Senegal in the 1970's and Mauritania in the 2000's	This technique limits wind erosion; protects arable land from sand; immobilizes sediments transported by the wind; increases infiltration and limits evaporation	Technical sheet of GTD
Stone bunds		Water retention; slower water flow; protection against water and wind erosion; byproducts (wood, hay); easy implementation; higher yields; higher soil humidity; sequestration of minerals and organic matter transported by water	Land insecurity; hard work; lack of stones; lack of transport means; risk on flooding in rainy years; training requirement to identify contour lines; requires collective work	Burkina Faso, in early 1980's.	If combined with organic matter input and other techniques (half-moons, zai holes): increased yields by 40 to 70%.	Bilgo 2014; Diguingue 2010; Dorlöchter 2012; Technical sheet of GTD
Contour bunding		Low equipment requirement; easy implementation; forage production; higher soil humidity; higher organic soil fertility; improved soil structure; higher infiltration	Easily destroyed and reconstructed; important maintenance required every year; risk of plants asphyxia; reduction of cultivated surfaces	Burkina Faso, Mali, Niger	Increased yields if associated with fertilizers, zai holes and/or half-moons. Farmers' adoption limited by hardness of work	Technical sheet of GTD
Weirs		Groundwater sources filling; biodiversity; improved soil fertilization; diversification of production (vegetables); extension of cultivated surfaces; protection against wind erosion; off-season crops production; improved water exploitation in dry periods; limit erosion in case of heavy rain	Requires preliminary study; implementation may be difficult depending on the level of degradation	Introduced in Chad by the German Cooperation	Yields increases (of about 60%) and recuperation of degraded land. Off-season production (vegetables): supplementary income and work all year long, limiting migrations.	BERCEF 2007 ; Adam Bachar 2011 ; Bender 2009; Dorlöchter 2012

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Networking of groundwater sources	Agro pastoral	Water and forage supply during transhumance				Interview CARI
Concerted management of water resource	Agro pastoral	Improved management of water sources on transhumance paths; Breeders interests acknowledgment		Mali (AVSF 2007-2011)		Cornu, 2011
Half moons		Higher water availability for plants; higher yields from the 1st year; low cost; reduced required quantity of seeds and fertilizers; production on degraded land; higher soil fertility; reduced soil losses; higher soil humidity	Land insecurity; work hardness; training requirement; organic matter availability; risk of flooding in rainy years; maintenance; fertilizer availability and transport	Burkina Faso. African farmers implemented this technique in response to the droughts in 1980.	Permits plants to survive temporary droughts. It can considerably enhance yields. Reduced soil hardness and water infiltration.	Berton, 2013 ; interview AVSF
Zai holes		Soil regeneration;; reduced required quantity of seeds and fertilizers; increased yields from the 1st year, increased soil fertility; reduced soil losses; higher soil humidity; maintenance of fertilizer in fields in case of heavy rain; reduction of water loss	Labor intensive; land insecurity; risk of water saturation in rainy years; required availability and transport of fertilizer; unsuitable on sandy soils	Burkina Faso, Senegal, Mali, Niger, Chad, Cameroon, Cape Verde, Zambia, Tanzania	Contributes to ensure production and food security. It significantly enhances yields. It may be limited by hard work and fertilizer availability.	Bilgo 2014 ; Dorlöchter 2012;Technical sheet of GTD
Mechanized zai holes		Reduction of labor intensity; regeneration of degraded land; relatively cheap equipment that can be shared between 3-4 farmers; concentration of rain water near the roots of cultivated plants		Burkina Faso. Validated with farmers before being diffused (AVSF)	Permits to recuperate degraded land, limit water flow and reduce work load. Farmers seem to be interested by this technique	Berton 2013 ; interview AVSF
Nardi trenches		Collection of water; improved soil structure for plants to reach nutrients; higher vegetation because trenches retain seeds transported by the wind				Dorlöchter 2012
Agricultural and silvopastoral benches		Re-vegetation from the 1st year; water supply for plants and filling of ground water sources; land protection against erosion; reduction of soil temperature	Relatively low economic profitability; hardness of work;		They have been implemented in Niger and have especially benefited to women.	Dorlöchter 2012
Filtering embankment		Extended water retention; sequestration of nutrients; re-vegetation; biodiversity; favor vegetable production (alimentation and extra source of income)	May require high level of engineering; relatively high costs compared to stone systems; may be damaged by rise in water level			Dorlöchter 2012
Mini-dams		Maintenance of water in fields for plants in dry periods; avoid flooding in rainy years; higher groundwater level; increased foods availability; higher farmers' revenue; land occupation of producers all year round; enhanced biodiversity	High quality planning and realization required; organized managing committee required for maintenance		Subsistence and vegetable productions increase. Generates work all year round, stabilizing local population and increasing revenues. Higher groundwater levels.	Dorlöchter 2012

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Water reservoir for vegetable production		Traditional technique well managed; higher yields; increased an diversified income (fruits, fishes…); improved food security; opportunities of activities during dry season; place of exchange and social cohesion; favored wild fauna and enhanced biodiversity; re-vegetation around the reservoir; filling of groundwater sources	In case of big reservoirs: high social and financial mobilization; refined knowledge; organized and regular maintenance; expensive equipment; predators of fishes;	Traditional technique, Burkina Faso, Mauritania, Niger	Higher vegetable yields, vegetation regeneration, water reserve, groundwater sources filling and enhanced biodiversity. But not necessarily access to required knowledge and not always able to work collectively. Possible conflicts between breeders and vegetable producers.	Technical sheet of GTD
Rope pump for vegetable production		Low investment; easy implementation; autonomy of users; no energetic dependence; possible use of drinking, irrigation and other activities water use; local construction material	Limited number of users (about 10 families); limited depth (max 40 meters)	Chad: an enterprise created in 1999		URD 2009
Reforestation of water source head		Enhanced water supply				Interview GRET
Mulching with Acacia tulmida or millet		Reduction of surface temperature; protection against erosion; higher phosphorus rate; increased soil organic matter; control of pests	Animals presence in dry season decrease quantity of mulch available		Mulching can increase yields by up to 50%.	
Early preparation and faster planting		Maximize the use of shortened rainy season; reduced risk of crop failure		Tanzania		Liwenga et al. 2012
Compost	Agro pastoral	Diversification of soil fertilization modes; Limitation of weed infestation; Higher soil humidity	Limited available quantities of manure or local biomass; Water requirement in dry periods		The use of natural fertilizers reduces costs and enhances products sanitary quality.	Dorllöchter 2012; CFSI 2014; interviews GRET and Terre et humanisme
Millet residues compost	Agro pastoral	Diversification of soil fertilization modes; Limitation of weed infestation; Enhanced soil fertility; Higher soil humidity; Valorization of local biomass	Limited available quantities of local biomass; Water requirement in dry periods		The use of natural fertilizers reduces costs and enhances products sanitary quality.	Wezel 2014
Introduction of alfalfa	Agro pastoral	Improved animals feeding; Market value; Fertilization		Chad		Interview URD
Fallow	Agro pastoral	Enhanced soil fertility; Soil maintenance	Increasing pressure on land			Wezel 2014
Protected areas	Agro pastoral	Soil restoration; Protection of sensitive zones	Increasing pressure on land; Free movement of animals			Interview AVSF
Reduced herds	Agro pastoral	Prevention against further environmental degradation		Tanzania		Liwenga et al., 2012
Animal mechanization (donkey)	Agro pastoral	Less hard work; Higher work efficiency; Fertilization		Endogenous practice revalorized since 2003 with PROMMATA		Interview AVSF
Improved compost		Enhanced soil fertility; Faster availability of nutrients; Competition to diseases		Mali: local association RHK	Good results on cowpea, peanut and maize. Can be used with vegetables and cereals.	Interview AVSF and RHK
Green manure		Improved soil structure and fertility; Higher soil humidity				Interview GRET

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Mulch		Soil protection against erosion; Higher nutrient soil content; Higher yields; Increased soil humidity	Animal consumption; Competition for use of crop residues (forage, construction); Hay increasingly often kept as forage		Improved soil parameters and enhanced biological activity. Higher yields observed.	Wezel 2014 ; Dorlöchter 2012 ; interview GRET
Seeds coating and dry sowing	Agro pastoral	Gain of 3 days on potential evaporation; Potential yield increase; Forage production for ruminants; Grain production for poultry; Reduced disease risk		North Burkina Faso: improvement of local technique	Seeds can germinate earlier.	Interview AVSF
Peasant seed exchange system	Agro pastoral	Protection of peasant seeds and genetic patrimony; Maintenance of varieties adapted to local conditions of soil and climate		West Africa: COPAGEM: association that promotes peasant seeds, raise awareness. Member organizations keep the seeds.		Interview CCFD
Mix of varieties		Risk diversification				Interview Terre et humanisme
Drought-tolerant crops		Higher resistance to droughts		Tanzania		Liwenga et al. 2012
Shorter-term crops or varieties		Reduced risk of crop failure thanks to shorter growth period		Tanzania, Mali Some seeds come from research centers (Senegal)		Liwenga et al. 2012
Drought-tolerant crops		Higher resistance to droughts		Tanzania		Liwenga et al. 2012
Shorter-term crops or varieties		Reduced risk of crop failure thanks to shorter growth period		Tanzania, Mali Some seeds come from research centers (Senegal)		Liwenga et al. 2012
Test and diffusion of local seed varieties		Generally very efficient varieties, adapted to local conditions; tolerance to droughts; higher yields; production valorization; improved living conditions of local populations; resistance to pests (caterpillars); higher incomes for farmers.		Niger, Ethiopia	Cooperatives of resilient varieties have been created. Radio emissions on climate changes and the use of such seeds are broadcasted.	RAC 2013
Production of local organic seeds		Higher yields; higher revenue for seed producers; access to organic seeds farmers can afford; high quality of seeds	Cost of sending to certification service	Mali: RHK (local association)	RHK provides its members with 80% of their onion seeds, which reduced onion production costs. Quality and adaptation to local conditions permitted to increase yields.	CFSI 2014
Improved local seeds multiplication		Seeds better fit local climatic conditions; resistance to pests and diseases		Madagascar: ACF and local partner		ACF 2015
Keeping local tree species		Maintenance of local biodiversity; maintenance of endangered tree species; recuperation of degraded land		Mali: local association RHK		CFSI 2014
Early sowing		Higher yields	Uncertain successfulness of vegetation implantation	Senegal		AVSF 2011

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Seeds soaking		Shorter germination period; more uniform production; vigorous plans; reduced time period between sowing and harvest; higher resistance to insects and fungi attacks; higher productivity	Less effect in wetter zones	Mali, Sudan, Ethiopia	Increase of yields by about 30% in Mali, Sudan and Ethiopia.	Aune 2011
Tree nur-sery for high demand trees		Trees for food, revenue, forage, wood, hedges and environmental protection	Animals may consume them			Aune 2011
Introduction of yam produc-tion		Yam is already part of the local diets but is not cultivated		Madagascar		Interview AVSF
Introduction of vegetable production		Production diversification; improved local diet		Madagascar		Interview AVSF
Introduction of castor oil plant production		Plant adapted to droughts and mineral-poor soils; harvest in October-November (hunger gap); high genetic diversity of seeds that can be re-used many times; oil is used for pharmacy, cosmetics and industry		Madagascar: 70 years ago it was common in Androy. 2013, a German interna-tional coope-ration and 20 farmers decided to bring it back.	Thanks to this supplemen-tary revenue, farmers can buy subsistence crops during hunger gap and even poultry and goats. They have also increased their cultivated surface.	Van Eeckhout 2015
Bio-pesticides		Trichoderma compete with cryptogamic diseases				Interview AVSF
Bio-insecticide		Neem tree oil repulses insects; reduced risk of insect attack		Currently being tested in Mada-gascar		ACF 2015; interviews ACF and AVSF
Natural plant-protection products		Reduction of risks of pest attacks		Mali: local asso-ciation RHK		Interview RHK
Integrated control of pests		Warmth and drying kill Insects; reduction of underground tem-perature; protection against erosion				Aune 2011
Introduction of small rumi-nants	Agro pastoral	Resistance to drought and wide range of foods for goats; Easy exchange; High repro-duction efficiency that permits to quickly reconstitute herds; High demand during Islamic celebrations;	Lower resistance of sheep to drought; Pos-sible damage of goats on grasslands as they select their food; Possible destruction of shrubs and trees by goats which eat their bud	Farmers in Sahel		Interview Salvaterra
Introduction of poultry	Agro pastoral	Small ruminant breeding strengthening; Quick revenue source especially for women		Chad		Interview URD
Introduction of beekeeping	Agro pastoral	Revenue diversification; Ali-mentation quality		Generally imple-mented in sub humid zones.		Interview AVSF
Selection of hardy cattle breeds	Agro pastoral	Breeds adapted to the lack of water	Lower productivity in favorable environment than for selective breeds	Farmers selec-tion; govern-ment farms	Not common in the sub-arid zone.	Interview AVSF
Fodder trees	Agro pastoral	Valorization of trees for livestock feeding; Protection against erosion		Already imple-mented before in sub-arid regions and became very common.		Interviews GRET and Salvaterra

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Agroforestry parks (ANR): Association Faidherbia aldida-crops	Agro pastoral	Reduced water input; Reduced fertilizer input; Forage production; Wood production; Higher crop yields; Avoidance of fallow; Maintenance/restoration of soil fertility; Limitation of water and wind erosion; Supplementary feed during hunger gap; Valorization of little exploited resources	Limitation of weeding by trees; Knowledge requirement for pruning; Maintenance; Slow tree growth; Possible animal consumption of trees in dry season; Free access to fruits, pods, leaves… in some regions; Tree implantation reserved to the owner in some areas	Burkina Faso, Niger, Malawi, Tanzania, Zambia	Crop yields increase, better water infiltration, better access to groundwater, higher organic matter content and higher nitrogen content. Enhanced biodiversity.	Dorlöchter 2012 ; Interview Salvaterra
Bourgou fields	Agro pastoral	Supplementary feed resource; Valorization of forage plants around ponds				Interview CARI
Grazing contracts	Agro pastoral	Improvement of soil fertility of fields; Access to forage for livestock; Avoidance of conflicts breeders/farmers		Implemented by populations for a long time		Wezel 2014
Collective organization of transhumance	Agro pastoral	Improved rangeland management; Avoidance of conflicts between breeders and farmers				Interview CCFD
Planned grazing	Agro pastoral	Limitation of overgrazing; Restoration of soil fertility; Stimulation of new growth	Collective organization required	Zimbabwe, spreading to Namibia. The government and civil society are working together on a national community-based grazing management policy.	Many communities have started using this approach in Zimbabwe	Interview Salvaterra
Rotational grazing	Agro pastoral	Limitation of overgrazing; Maintenance of pastureland in the long term; Low workforce requirement; Organic fertilization; Increased quantity and quality of forage; Increased animal productivity; Higher income; Higher soil humidity/lower evaporation; Lower runoff (plant cover); Enhanced plant biodiversity	Global farm planning required; Expensive equipment (fences or surveillance); If not well managed: spreading of less palatable plants	Technique implemented by breeders in sub humid zones. Diffusion from external development actors	More animals are fed with the same surface. Adoption may be limited because it may exclude transhumant populations; expensive installation of fences and through; annual variability of forage resources availability; conflicts for land.	Technical sheet of GTD
Hay production	Agro pastoral	Supplementary feed during hunger gap (storage of food resource); Facilitated work organization for dairy herds (milking 1-2 times/day); Low cost; Enhanced animal production; Higher income (hay can be sold); Limitation of overgrazing; Limitation of vegetation degradation by animals	Hay quality often insufficient to fulfill herds' needs; In case of low rainfall: low production and hard work; supplementary work; Low work force availability because of subsistence products harvest at the same time; Often land ownership requirement or collective organization	Burkina Faso, Mali, Niger, Cameron, Senegal, Chad. Old technique in occidental Asia and Western Europe. Development in Africa after 1970 droughts. Some associations (ASFDI; APESS in Sahel) have stimulated its development.	This technique provides feed resource when grasslands are unavailable. It improves livestock feeding in quantity and quality and stimulates its production. It also limits overgrazing.	Aune 2011 ; interview Salvaterra
Urea treatment of hay	Agro pastoral	Improvement of low quality hay digestibility (for instance for rice); Higher nitrogen content; Valorization of residues	Time requirement for animals to get used to it			Aune 2011
Mineral supplementation for dairy animals	Agro pastoral	Increased milk production		Sudan	Significant milk production increases observed in Sudan.	Aune 2011
Supplementation of millet bran	Agro pastoral	Increased protein content of animal diets; Increased milk production				Aune 2011

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Direct sowing of local tree species		Tree regeneration; biomass production for forage (longer grazing possible); enhanced biodiversity that improves grassland quality		Burkina Faso: Italian NGO REACH	Trees permit to reconstitute grass cover from the first year after plantation. 5 to 30 times higher biomass production. It constitutes quality forage. Animals can graze longer.	CILSS 2009
Assurance approaches		Better valorization of production in off-season		Niger		Aune 2011
Community granary		Ensure food supply during hunger gap				Blein 2011
Dissemination of varieties selected by farmers		Varieties adapted to local climatic and soil constraints; farmers trust other farmers more than technicians		Madagascar: endogenous practices diffused by international NGOs	Lead farmers have contributed to change agricultural practices in their communes. Pigeon pea introduced although it was subject to taboos ten years ago. Adoption of sweet varieties of lima bean (konoke) is expanding.	Lheriteau et al. 2014
Farmers Field School		Knowledge exchange; farmers trust other farmers more than technicians; training in farmers own fields; exchanges between farmers and institutions		Madagascar: diffusion of endogenous practices organized by international NGOs (ACF…).	Shows effectiveness and seems to help agroecology to be better taken into account by authorities, especially on seeds production policy.	Lheriteau et al. 2014
Field school		Learning through observation and experimentation; dissemination of new technologies; farmers learn how to make their own diagnosis		ACF and local partner		Aune 2011
Local research-innovation platform		Participatory research: include beneficiaries in research; diffusion by beneficiaries of research results; enhance agroecology recognition		Zimbabwe	Zimbabwe: farmers, researchers and farming organizations involved in conservation agriculture for maize.	Interview ACF
Community consultation body for natural resources management		Filling of groundwater sources ; reforestation ; vegetable production ; higher rainfall cereals yields		Mali: GRDR (French NGO)		Berton 2013
Milk collection system		Production valorization; supplementary revenue to invest in animal purchase		Mauritania, Senegal, Mali: NGO projects	Does not work very well so far.	CFSI 2014 ; interview CARI
Honey house		Farmers decide on the price of honey; collective organization; possible sell on local markets; local consumers have constant access to honey; pollinators favor other productions		Burkina Faso: local association (APIL)	Volume of honey collected has increased from 7 to 37 tons between 2008 and 2013.	CFSI 2014
Short food supply chain		Closer link between farmers and consumers; better production valorization		From external examples		Interview CCFD
Development of meat sector		Professionalization; better production valorization; improved collective organization				Interview CCFD

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Storage buildings from local materials		Reduced losses of production; improved food security; better access to markets for farmers; purchase of foods they do not produce; improve nutritional quality of diets				Interview ACF
Participative certification system		Lower cost of certification for producers; lower prices of organic products for consumers; better valorization of organic products; encourage other producers to produce organic	Burkina Faso, Mali, Niger, Cameron, Senegal, Chad. Old technique in occidental Asia and Western Europe. Development in Africa after 1970 droughts. Some associations (ASFDI; APESS in Sahel) have stimulated its development.	This technique provides feed resource when grasslands are unavailable. It improves livestock feeding in quantity and quality and stimulates its production. It also limits overgrazing.	Aune 2011 ; interview Salvaterra	

Appendix 6: Agroecological innovations inventoried in sub humid regions of Africa

All the agroecological practices mentioned for the sub humid zone are presented here. You can see which ones have been mentioned specifically for mixed crop-livestock systems (column "Referent system"). Practices are organized depending on the components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow), collective organization (red).

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Agroforestry		Organic matter supply; protection against water erosion; enhanced biodiversity (plants and animals including insect and bird pollinators; lower surface temperature; limited evaporation; better filling of water sources; maintenance or increase of yields; byproducts (wood, fruits…); reduces or suppresses inputs purchase -> economic interest; production diversification	Lack of political willingness; chemicals lobbying; land insecurity	DRC, Togo, Burkina Faso, Senegal. Association APAF: project to popularize agroforestry techniques since the 1990's. And Salvaterra.	In Togo: 29 850 agroforestry fields implemented between 2001 and 2004 (in general coffee/cocoa and subsistence crops)., with increased yields observed and soil fertility improvement.	Scholle 2015 ; Bilgo 2013 ; interviews ACF and AVSF
Assisted Natural Regeneration		Limited water erosion; Enhanced vegetation; Protection against soil degradation; Increased quantity of organic matter and nitrogen in soils; Low cost of implementation; Additional income from non woody products	Land insecurity; Required surveillance at the beginning in dry season to protect plants from animals			De Witte 2013 ; interview AVSF
Hedgerows		Protection against water and wind erosion; better water infiltration; protection of plots against animals; higher crop yields; biomass supply; byproducts (fruits, wood…); enhanced biodiversity (beneficial insects, birds…); protection of crops against wind;	Transport of plants; high maintenance and protection required; water requirement; work load; supplementary cost if purchase of plants; may reduce cultivated surface; fire risk	Togo, Burkina Faso. Traditional technique in many countries	Increased crop yields. Generates supplementary production and permits to avoid hedge reconstruction every year.	De Witte 2013 ; Technical sheet GTD
Bench terracing		Reduced soil erosion; Increased crop production; Safe cropping operations on slopes	Only on slopes steeper than 15% and where soil conditions are favorable.			Tumbo 2010

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Contour bunding		protection against water erosion; better water infiltration; few material needed; higher yields when associated with agroecological practices such as manure or compost use; forage for animals from plants stabilizing bunds; higher soil humidity; higher organic fertility of soils; better soil structure	need of maintenance on clay soils; decrease of cultivated surface; increased risk of flooding of crop with the maintenance of water in case of heavy rain	Togo		Scholle 2015
Permeable stone dam		protection against water erosion; better water infiltration; development of natural vegetation	High level of technical knowledge required; availability of stones; maintenance required	Togo		De Witte 2013
Stone bunds		Water retention; slower water flow; protection against water and wind erosion; byproducts (wood, hay); easy implementation; higher yields; higher soil humidity; sequestration of minerals and organic matter	Hard work; stones availability; risk of flooding in case of heavy rain; technical knowledge required; maintenance	Togo		De Witte 2013
Water reservoir	Mixed crop-livestock	Water supply for animals in dry season; Reduction of water erosion; Vegetable or short-term cereals production	No cultivation around the reservoir; Maintenance; Training in irrigation techniques; Risk of water losses (evaporation and infiltration)	Togo		De Witte 2013
Pond structures	Mixed crop-livestock	Water supply for animals in dry season; Vegetable production in dry season; Filling of groundwater source by infiltration	Disease risk (animals or bacteria pollution); Important maintenance	Togo		Orlhac 2013
Mechanized zai holes		Reduction of labor intensity; regeneration of degraded land; relatively cheap equipment that can be shared between 3-4 farmers; concentration of rain water near the roots of cultivated plants		Burkina Faso. Validated with farmers before being diffused (AVSF)	Recuperation of degraded land, limited water flow; reduced work load. Farmers seem to be interested by this technique	Interview AVSF
Sand dams		Drinkable water available all year long; possible erosion control; supplementary source of income (sand); can remain for a long time if well maintained	Not implementable everywhere; external help required for site analysis; work load for construction; cost of implementation	Togo		De Witte 2013
Fanya Juu Terraces		Collective organization; yield increase by 50%; feed production (grass); material production for handicraft (grass); higher soil humidity; reduction of water erosion	Work load for installation; Limits soil working; reduction of cultivated surfaces; flooding risk;	Kenya, Ethiopia, Tanzania, Uganda, Mali, Senegal, Burkina Faso. Appeared in the 19th century with farmers from Kenya in response to droughts.	Increased yields if combined with organic matter supply. It allows for improving infiltration of rain water and sequestration of sediments which are rich in minerals and organic matter.	Technical sheet GTD
Reforestation of water source head		Enhanced water supply				Interview GRET

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Local committee for water management		More efficient irrigation management; better access to water for farmers; conflicts management	Lack of communication between different levels of organization; lack of funds	Tanzania: Project Gret/ Sokoine University of Tanzania, since 2009.	Collective actions and innovations. Water users work together to release collective economic benefits. Every farmer can have access to water during one week, and no more crop is lost. Written constitution made all stakeholders aware about collective rules. In addition, Group common plot and fees generate income for each Group.	Orlhac 2013
Compost	Mixed crop-livestock	Diversification of soil fertilization modes; Limitation of weed infestation; Higher soil humidity; Valorization of local biomass	Availability of manure or local biomass; Water requirement in dry periods		The use of natural fertilizers reduces costs and enhances products sanitary quality	Interview GRET
Animal mechanization (donkey)	Mixed crop-livestock	Less hard work; Higher work efficiency; Fertilization		Endogenous practice revalorized since 2003 by PROMMATA		Interview AVSF
Improved compost		Enhanced soil fertility; Faster availability of nutrients; Competition to diseases		Mali: Local association RHK	This technique has given good results on cowpea, peanut and maize. Can be used with vegetables and cereals.	Interview AVSF
Liquid compost				DRC		Scholle 2015
Green manure		Improved soil structure and fertility; Higher soil humidity		(Gret)		Interview GRET
Cover crops				DRC		Scholle 2015
Grass strips		Maintenance of local plant species; protection against erosion; better water infiltration; easy implementation; maintenance of water and organic matter it contains in fields; forage, compost, mulching or fences; better valorization of rain water and increased soil humidity; higher yields of cereals	Plantation during a busy period: lack of workforce for preparation; risk of competition with crops; limited by grazing animals; benefits after 3 years	Togo		De Witte 2013
Mulch-based cropping system		Enhanced soil fertility; Higher soil humidity; weed control	Free movement of animals; land insecurity; fire risk	Cameron		
Minimum tillage		Easy implementation; Time and energy saving; Increased yields; Early crop maturity; Crop residues as forage; Higher income; Limited soil degradation by wind and water; Reduced soil compaction; Organic matter accumulation; Lower evaporation; Enhanced water infiltration	Need of mechanical or animal workforce; High cost of animals and equipment maintenance; Higher risk of weed infestation; Soil saturation in rainy years	Traditional African farming practice, developed in Sub-Saharan Africa in the 1980's	Adoption is sometimes limited by equipment cost, work hardness, high weed pressure	Technical sheet of GTD

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Association cereal-cowpea		Favors cowpea development; weed control by cowpea	Availability of seeds quality	Implemented in sub-arid zones.	Could be interes-ting in sub humid zones where weeds in cereals problem is cru-cial. Good results in Nigeria where there is a market for cowpea.	Aune 2011 ; interview AVSF
Crop rotation		Preserved and enhanced soil fertility; Improvement of soil structure; Pests and pathogens control				Interview ACF
Peasant seeds exchange system	Mixed crop-li-vestock	Protection of peasant seeds and genetic patrimony; Main-tenance of varieties adapted to local conditions of soil and climate		West Africa: COPAGEM: pro-motes peasant seeds, raise awareness. Member organi-zations keep the seeds.		Interview CCFD
Introduction of legumes	Mixed crop-li-vestock	Compensation for cereal prices volatility; Enhance soil fertility	Market	Togo (AVSF)		Interview AVSF
Strengthening of vegetable production	Mixed crop-li-vestock	Valorization of production in dry season	Low water availability; Closure of wells	Togo (AVSF)		Interview AVSF
Improved local seeds multipli-cation		Seeds better fit local climatic conditions; resistance to pests and diseases		GRET project (2009-2011)		GRET 2011 ; interview GRET
Shorter-term crops or varie-ties		Reduced risk of crop failure thanks to shorter growth period		Tanzania, Mali Some seeds come from research centers (Senegal)		Interview AVSF
Drought-tole-rant crops		Adaptation to climate change		Côte d'Ivoire		Comoe 2010
Introduction of cassava		Diversification of production; nutritional value of diets; diversification of risks				Tumbo 2010 ; interview CARE
Combination wet/dry sea-sons crops						Interview Agrisud
Bag cultivation		Easy implementation; low cost; enhance families' food security; surface optimization		Kenya		Interview CARE
Bio-insecticide		Neem tree oil repulses insects; reduced risk of insect attack		Currently being tested in Mada-gascar (ACF)		Interviews AVSF and ACF
Fodder trees	Mixed crop-li-vestock	Valorization of trees for lives-tock feeding, including in dry season; Protection against erosion; Increased animal pro-duction; Easy implementation; Byproducts and services	Lack of species appro-priate to different agro-ecological zones; Lack of functioning seed supply systems; Knowledge requirement	Already imple-mented before in sub-arid regions and became very common. Researchers, extension services and farmers have developed and promoted fodder tree practices in many different countries and contexts.	Fodder trees are important feed sources for lives-tock in a wide range of farming systems in Africa.	Franzel 2014

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Hay production	Mixed crop-livestock	Supplementary feed during hunger gap; Facilitation of work organization for dairy herds (milking 1-2 times/day); Low cost; enhanced animal production; Additional income ; Limitation of soil degradation by overgrazing; Limitation of vegetation degradation by animals	Hay quality often insufficient to fulfill herds' needs; In case of low rainfall: low production and hard work; Supplementary work; In case of no grazing: no or little manure on fields; low work force available because of subsistence products harvest at the same time; Ownership of land or collective organization	Burkina Faso, Mali, Niger, Cameron, Senegal, Chad. Old technique in occidental Asia and Western Europe. Development in Africa after 1970 droughts. Some associations (ASFDI; APESS in Sahel) have stimulated its development.	This technique provides feed resource when grasslands are unavailable. It improves livestock feeding in quantity and quality and stimulates its production. It also limits overgrazing.	Aune 2011 ; interview Salvaterra
Valorization of crop residues	Mixed crop-livestock	Alternative feed source; Valorization of local biomass		(AVSF)		Interview AVSF
Faidherbia parks	Mixed crop-livestock	Low equipment requirement; reduced water input; Reduced fertilizer input; Forage production (pods and leaves); Wood production; Low cost; Higher crop yields; Avoidance of fallow; Maintenance/restoration of soil fertility; Limitation of water and wind soil erosion; Positive effect on crops after 4 years; Supplementary feed during hunger gap; Valorization of little exploited resources; Reduced hydric stress for plants	Limitation of weeding by trees; Knowledge requirement for pruning; Maintenance every year; Slow tree growth; Possible animal consumption of trees in dry season; Free access to fruits, pods, leaves…in some regions; Tree implantation reserved to the owner in some areas	Burkina Faso, Niger, Malawi, Tanzania, Zambia	Crop yields increase, better water infiltration, better access to groundwater, higher organic matter content and higher nitrogen content because Acacia is a legume. If well managed, Acacia is adult within 4 years. It also permits to enhance biodiversity.	Scholle 2015 ; interview Salvaterra ; interview AVSFs
Rotational grazing	Mixed crop-livestock	Limitation of overgrazing; Maintenance of pastureland in the long term; Low workforce requirement; Organic fertilization; Increased quantity and quality of forage; Increased animal productivity; Higher income; Higher soil humidity/lower evaporation; Lower runoff (plant cover); Enhanced plant biodiversity	Global farm planning required; Expensive equipment (fences or surveillance); If not well managed: spreading of less palatable plants	Technique implemented by breeders in sub humid zones. Diffusion from external development actors	More animals fed with same surface. Adoption may be limited because it may exclude transhumant populations; expensive installation of fences and through; annual variability of forage resources availability; conflicts for land.	Technical sheet GTD
Regulation of animal free movement	Mixed crop-livestock	Limitation of animal damages on crops; Dialogue farmers-breeders; Identification of sensitive zones	Absence of fences	Togo (AVSF)		Interview AVSF
Local land management charter	Mixed crop-livestock	Control of conflicts linked to land use; Herds mobility and access to grasslands and water sources assurance		Burkina Faso: municipalities, research (Cirdes, Cirad) and legal experts.		INRA 2014
Biogas slurry	Mixed crop-livestock	Alternative to deforestation; Reduction of greenhouse gas emissions; Renewable energy; Valorization of manure; Fertilizer production	High investment	Mali: local association and AVSF, 2012-2015.	So far 100 dairy stables have been equipped in Mali.	Roesch 2014 ; interview AVSF
Re-vegetation of stone bunds		Plantation of Piliostigma reticulate that can be given as feed to animals				Interview AVSF
Promotion of agroecological production modes	Mixed crop-livestock	Knowledge exchange between farmers; production valorization; sector organization		Senegal	From the 1st year, involvement of 20 groups of vegetable producers permitted to rationalize commercialization of vegetables with higher prices.	CFSI 2014

Practice	Referent system	Major advantages	Some limits	Where?	Results	Reference
Cooperatives for the use of agricultural equipment (CUMA)		Faster work: to face reduction of growth seasons; collective organization	Farmers do not necessarily understand the concept of CUMA; young animals purchased that are not efficient in the first year	Mali: AVSF and local association ICD, 2007-2014.	286 CUMA created in different regions, many remain. They permit to efficiently equip farmers who do not have access to credit. They contribute to food security of families and rural world structuration.	AVSF 2014 ; interview AVSF
Multi-actors research platform		Involvement of the different actors in research objectives definition		Tanzania: local authorities, NGOs, local farmers leaders (CARE)		Interview CARE
"Champion farmers"		Farmers teach other farmers: more efficient diffusion of practices	"champion farmers" are generally not the most vulnerable; financial capacities of most vulnerable farmers limit their participation	Tanzania: practices from other communities. These practices are not new but were not necessarily used.	Good results (CARE)	Interview CARE
Community consultation body for natural resources management		Filling of groundwater sources ; reforestation ; vegetable production ; higher rainfall cereals yields		Mali: GRDR (French NGO)		Berton 2013
Mini cooperative dairies		Higher prices for farmers; farmers can benefit from microcredits	Demand is higher than offer	Senegal	Collect zones extend and higher prices stimulated milk production. Supply is constant during wet and dry season.	CFSI 2014
CSA system		Stable and regular outlet for vegetable producers; confidence between farmers and consumers	Demand too important for offer;	Benin: Hortitechs (local association)	This system secure producers.	CFSI 2014
Participative certification system		Lower cost of certification for producers; lower prices of organic products for consumers; better valorization of organic products; encourage other producers to produce organic				

Appendix 7: Agroecological innovations inventoried in humid tropical regions of Africa

All the agroecological practices mentioned for the humid tropical zone are presented here. You can see which ones have been mentioned specifically for agroforestry systems (column "Referent system"). Practices are organized depending on the components that are affected by climate change: landscape (dark green), water (blue), soil (light green), seeds and plants (orange) and animals (yellow), collective organization (red).

Practice	Referent system	Major advantages	Some limits	Origin	Results	Reference
Reforestation	Agrofo-restry	Diversification of income sources; Protection against erosion; Fertilization	Droughts; Animals free movements; Lack of maintenance	Madagascar (AVSF)		Foubert 2014 ; interview AVSF
Plantation of Eucalyptus	Agrofo-restry	Wood and charcoal production; Protection of slopes against erosion; Protection against silting of bottomlands; Easy management and exploitation of species; Rapid growth on all types of soil	Difficult specie to elimi-nate; Soil weakening; Risk of competition with subsistence crops	Common prac-tice in Madagas-car. Diffusion by AVSF.	Eucalyptus has been planted at the top of slopes. Implantation is generally indivi-dual, except for some collective planning schemes.	Foubert 2014
Hedgerows		Soil quality improvement close to crops; protection against wind erosion; humidity maintenance; forage production (Cajanus cajan), wood production; green manure; sometimes human alimentation (flour from Cajanus grains); reduced maintenance	Acacia requires a lot of organic matter and phosphorus, brings a lot of shade and has a bad quality of wood; Cajanus is sensitive to flooding and frost and must be replaced every 3-4 years	Madagascar (AVSF)	Hedgerows implantation is generally indivi-dual, except for some collective planning sche-mes.	Foubert 2014
Contour lines cultivation		Limitation of erosion	Land constraints (fields shape); equipment and work load; reticence of some farmers to invest in "unproductive" plantations			Interviews Agrisud and Etc terra
Participa-tive map making for bottomlands water mana-gement	Agrofo-restry	Collective organization; Water resource managements	Difficult organization of communities, often not from intern initiative	AVSF		Interview AVSF
Basket com-post	Agrofo-restry	Soil fertilization		Madagascar		Interview AVSF
Cover crop: Brachiaria	Agrofo-restry	Restoration of degraded land; Higher crop yields		Madagascar (AVSF)	After 2 years maximum, crop yields double.	Technical sheet ISTOM ; Inter-view AVSF
Cover crop: Stylosanthes	Agrofo-restry	Soil protection against erosion; Once cut, slow regrowth: time let for the crop to grow; Less workload than for Brachiaria	Efficiency on soils with minimum fertility level	Madagascar (AVSF)		ISTOM 2013 ; interview AVSF
Cash cover crops	Agrofo-restry	Supplementary income source; Protection against erosion				
	Sensiti-vity to droughts; Animals free mo-vement; Lack of mainte-nance	Madagascar		Foubert 2014 ; interview AVSF		
Association orchard-Ara-chis	Agrofo-restry	Protection against erosion; Feed source; Time saving on weeding		Madagascar	Well adopted by farmers	Interview AVSF
Alley cropping system	Agrofo-restry	Soil fertilization; Yields stabi-lization			More stable yields have been observed with this technique.	Lasco et al. 2014

Practice	Referent system	Major advantages	Some limits	Origin	Results	Reference
Grass strips: Brachiaria	Agrofo-restry	Protection against erosion; Avoidance of bottomlands' silting; Important biomass production; Soil restructuration		Madagascar		Foubert 2014 (AVSF)
Fertilizer Tree Species (FTS)	Agrofo-restry	Soil fertilization; Higher crop yields				Lasco et al. 2014
Introduction of legumes after storms	Agrofo-restry	Enhanced soil fertility		Madagascar (AVSF)		Interview AVSF
System of Rice Intensification (SRI)	Agrofo-restry	Yield increase; Reduced external inputs use; Reduced quantity of water used; Enhanced resistance to pests and diseases	Workload (weeding and harvest); Attention requirement; Knowledge requirement	Madagascar: French agronomist with local farmers, in the 1980's.	Still few farms implement this system. There exist some popularization campaigns and research is going on. However many farmers in AVSF projects implement some principles of the SRI.	ISTOM 2013 ; Technical sheet ISTOM ; interview AVSF
Compost		Soil fertilization; valorization of local biomass; low cost; easy implementation	Farmers often need technical training; work time; hardness of organic matter transport	Madagascar	An increasing number of farmers are composting.	Delille 2011 (AVSF)
Manure ditch		Enhanced manure quality	All farmers do not have animals	Madagascar: traditional technique, diffusion with AVSF since 2000.		ISTOM 2013 ; Technical sheet ISTOM
Crop rotations		Preserved and enhanced soil fertility; Improvement of soil structure; Pests and pathogens control	In Sahel, small plots of cereals prevail. Farmers cannot always afford not to grow cereals some years.	Madagascar (AVSF)		Interview ACF
Minimum tillage		Easy implementation; Time and energy saving; Increased yields; Early crop maturity; Crop residues as forage; Higher income; Limited soil degradation by wind and water; Reduced soil compaction; Organic matter accumulation; Lower evaporation; Enhanced water infiltration	Need of mechanical or animal workforce; High cost of animals and equipment maintenance; Higher risk of weed infestation; Soil saturation in rainy years	Traditional African farming practice, developed in Sub-Saharan Africa in the 1980's	Adoption is sometimes limited by equipment cost, work hardness, high weed pressure	Technical sheet GTD
Short-term rice varieties		Better concordance with rainfall patterns; does not stay long in fields: better chance to avoid storms	Disappearance of long-term varieties; imported varieties: risk	Madagascar: Salvaterra and AVSF Seed selection by Japanese		Interview Salvaterra
Off-season crops in bottomlands		Crop diversification; valorization of arable land; fertilization; repartition of harvests in the all year		Madagascar		ISTOM 2013 ; Technical sheet of ISTOM
Rainfall rice on Tanety		Crop diversification; valorization of arable land; diversification of income sources;	Work load; required seed quality to get good yield; minimum fertility and water retention of soils required; favorable climate required (regular rain); yield dependent on rainfall -> very variable	Madagascar: This technique has been implemented by farmers for decades. Diffusion by AVSF	It is a new opportunity for many vulnerable farmers with poor soils. Farmers have adapted this technique to their own situation.	ISTOM 2013 ; Technical sheet of ISTOM
Crop-livestock integration	Agrofo-restry	Valorization of byproducts; Animal feeding; Soil fertilization		Madagascar (AVSF)		Dellile 2011 ; interview AVSF
Agrosilvopastoral systems	Agrofo-restry	Organic fertilization				Interview ACF
Introduction of beekeeping	Agrofo-restry	Diversification of income sources; Honey harvest without hive destruction; Nutritional value	High cost of investment	Madagascar (AVSF)	Good results (AVSF)	Fourbier 2014 ; interview AVSF
Introduction of fish breeding	Agrofo-restry	Diversification of productions; Fertilizer source	Not feasible on all types of farms	Madagascar (AVSF)		Dellile 2011 ; interview AVSF

Practice	Referent system	Major advantages	Some limits	Origin	Results	Reference
Cover crops as forage	Agrofo-restry	Valorization of forage source; Protection against erosion	Animals free movement	Madagascar (AVSF)		Rajaobelina 2014
Animal health service for poultry	Agrofo-restry	Limitation/control of poultry diseases		Madagascar (AVSF)		Technical sheet of ISTOM ; interview AVSF
Shelters for livestock	Agrofo-restry	Limitation of animals mortality (protection during storms)	High cost of investment	Madagascar (AVSF)		Interview AVSF
Forage com-mercialization	Agrofo-restry	Diversification of income sources; Valorization of surplus		Madagascar (AVSF)		Interview AVSF
Honey house		Stimulation of honey pro-duction thanks to the outlet; improved local diets		Madagascar (AVSF)		Interview AVSF

Appendix 8: Glossary of agroecological practices[1]

Agricultural and silvopastoral benches: rectangular device made of soil or stones or both. It can be either permeable or impermeable.

Agrosilvopastoral systems: conservation agriculture with integration of small ruminants.

Alley cropping system: lines of trees with crop cultivation in between.

Animal health service for poultry: private service for poultry vaccination.

Animal mechanization: use of donkeys for agricultural work.

Assisted Natural Regeneration: protection and preservation of natural tree seedlings, to convert degraded lands into productive forests.

Association orchard-Arachis: use of Arachis as vegetative cover, valorized as feeds for animals.

Assurance approaches: credit given by local institution to peasants who provide grain which is stored until they can reimburse the credit. Grain price is generally higher at this time of the year than at harvest time.

Bag cultivation: bags containing soil and stones in which vegetables are planted.

Basket compost: decomposable home garbage, garden and farm waste and leguminous leaves are allowed to rot in baskets half-buried in garden plots as a method of producing organic fertilizer.

Bench terracing: relatively steep land is transformed into a series of level strips running across the slope. It retards erosion losses and makes cropping operations on these slopes possible and safe.

Biogas slurry: animal excrements are bio digested to produce energy. Effluents can be valorized as organic fertilizer.

Bio-insecticide: use of neem oil against insects such as grasshopper.

Bio-pesticides: enrichment of compost with trichoderma against cryptogamic diseases.

Biological dune fixing: to complement mechanical dune fixing. Sand is maintained thanks to trees and perennial herbaceous vegetation.

Borders: small ridges built with soil and residues around the edge of a small plot. Water from the canal is diverted into the plot, and held long enough by the ridges to deeply infiltrate.

Bourgou fields: valorization of forage plants growing around ponds.

Californian irrigation system: PVC pipes are buried to bring water to distribution spots allocated in the farm.

Cash cover crops: plantation of clove, coffee, essential oils plants, citruses as vegetative soil cover.

"Champion farmers": one or two "model farmers" are identified to promote agricultural practices. They are farmers with influence in the society.

Choice of drought-tolerant local varieties of cereals: plantation of plants that have a higher resistance to droughts (such as lablab, sorghum or cassava).

Collective irrigation management: rational mutual irrigation management with collective water storage, based on cultivated plants' needs.

Collective organization of transhumance: rationalization, identification of transhumance paths.

Combination wet/dry season crops: combination of productions that take place in different seasons in order to produce and have work all year round.

Community consultation body for natural resources management: popularization of conservation techniques of water and soils; production techniques for cereals and vegetables; and introduction of new varieties (adapted to hydrologic equipment in rice production).

1 Based on the information collected in the interviews and literature review

Community granary: during hunger gap, farmers can borrow millet bags that they will give back once they have harvested, with a small interest.

Composting: let decompose to then recycle organic matter as a fertilizer and soil amendment.

Concerted management of water resource: collective management of water for pastoral use to secure transhumant breeding mobility. It takes into account existing traditional management laws as well as the State law.

Contour bunding: device made of soil to collect rainwater and/or limits water flow's damages on soil and crops.

Contour lines cultivation: field operations are done on the contour, or at right angles to the natural slope to reduce soil erosion, protect soil fertility, and use water more efficiently.

Cooperative: farmers gather to process and sell their production.

Cooperatives for the use of agricultural equipment (CUMA): equipment is shared in groups of 5 to 8 families. Famers get training on the use of this equipment.

Crop-livestock integration: valorization of plants and animals' byproducts; use of organic manure for crop production.

Crop rotation: a series of different types of crops are grown in the same area in sequential seasons.

Cover crop: plantation of herbaceous plants to cover the soil.

Cover crop as forage: valorization of cover crop for animal feeding.

CSA system: short food supply chain. Organic farmers and consumers sign a contract for a given period of time. Consumers commit to buy farmers their products and farmers commit to produce foods for their consumers.

Date palm composting: leaves of date palm are crushed to accelerate decomposition.

Date palm mulching: covering the soil with date palm residues.

Direct sowing of local tree species: direct sowing of local tree species to restore degraded land.

Dissemination of varieties selected by farmers: distribution of seed vouchers that can be used in local seed shop to get one kilogram of seeds. The seeds are selected by farmers and adapted to local soil and climate conditions.

Double digging: type of strip tillage (about 30 inches deep). Maize is then planted into this strip of soil, and the area between strips can be planted in beans, lablab, cowpeas, or pigeon peas.

Drip irrigation system: network of tubes and emitters that allow water to drip to the roots of plants.

Early sowing: sowing before first rain, to get higher yields.

Early preparation and faster planting: innovation in sowing phase, to maximize the use of shortened rainy season.

Faidherbia parks: animals can graze in agroforestry parks based on the specie Faidherbia (high nutritional quality of leaves).

Fair: farmers can sell directly their production in fairs.

Fallow: land is left unseeded for one or more growing season(s).

Fanya Juu Terraces: several ditches are dug on a slope with a low soil wall under it, mainly to collect run-off water. These low walls are stabilized with grass than can provide animals with feeds.

Farmer Field School: knowledge exchange system. Training sessions for farmers are organized in villages. Farmers also get the change to visit lead farmers farms to learn about their practices.

Fertilizer Tree Species (FTS): plantation of legume trees that fertilize the soil.

Field school: training farmers through observation and experimentation.

Filtering embankment: permeable small stone layers for degraded land restoration.

Fodder trees: valorization of trees that provide forage for animals.

Forage commercialization: farmers sell surplus of forage to get supplementary revenue.

Grass strip: planting or sowing local grass species along contours, to slow run-off water flow, increase infiltration and retain sediments.

Grazing contracts: contract between breeders and farmers. It defines when breeders are allowed to graze their animals on the farmer's fields. Animals graze in dry period and move away at the beginning of wet season to let farmers cultivate.

Green manure: crop residues are left in the field to serve as mulch and fertilizer.

Half-moon: holes are dug with a half-moon shape to grow crops, with a protecting low wall of soil. It permits to collect run-off water.

Hay production: natural or cultivated grass is harvested green, dried and stored in balls. It constitutes feed resources for the end of dry season.

Hedgerows: plantation of trees and shrubs around or inside plots to prevent water erosion and sometimes animal damages.

Honey house: cooperative for processing and selling of honey. Prices are fixed by farmers in general assemble.

Improved composting: compost is enriched with either Trichoderma or natural phosphates. Trichoderma accelerates lignin and cellulose degradation and compete with cryptogam diseases. Natural phosphates acidify and enhance available phosphate.

Improved local seeds multiplication: purification and multiplication of local adapted seeds.

Integrated control of pests: stems are cut right after harvest and left on soil surface.

Intercropping: two or more crops are grown simultaneously on the same field.

Jessour irrigation system: several dams are constructed to capture runoff water and alluvium. Soil accumulated behind the dam is then used to cultivate or implant fruit trees.

Keeping local tree species: ploughing and direct sowing of local tree species to **restore degraded land.**

Liquid compost: use of liquid extracted from compost as fertilizer.

Local committee for water management: collective work on irrigation systems.

Local land management charter: innovative organization to better manage increasing conflicts linked to the use of agro-silvo-pastoral resources and complement traditional laws when land pressure becomes too important.

Local research-innovation platform: work with research centers and farming organizations to increase agroecology credibility.

Manure composting: manure from livestock is composted.

Manure ditch: ditches used for storage and improvement of manure (for instance composting in several layer that combine plant and animal material).

Mechanical dune fixing: installation of palisades to slow winds and immobilize the sand it transports. It aims at avoiding silting of cultivated land and/or natural ponds.

Mechanized zai holes: use of animal power for digging of zai holes to reduce peasants' workload.

Milk collection system: installation of collect points in more marginal areas. Contracts secure milk supply and revenue for farmers. Farmers commit to deliver every day their surplus of milk that can be commercialized. In return, the enterprise commits to collect their surplus.

Mineral supplementation for dairy animals: to complement forage that has low mineral content: give access to salted stone to lick for dairy animals.

Mini cooperative dairies: 30 to 40 farmers own the cooperative. They gather the milk produced in the area. They get revenue that is fixed with all the actors of dairy sector.

Mini-dams: medium size dams constructed in bottom lands to retain run-off water.

Minimum tillage: superficial soil working with crop residues left at the top. It aims at limiting soil erosion and enhancing water infiltration.

Mix of varieties: mixing varieties in sowing phase.

Mulch: cover the soil with branches of natural or cultivated vegetation, after harvest.

Mulch-based cropping system: sowing under vegetative cover.

Multi-actors research platform: consultation between different actors to determine research objectives (local authorities, NGOs, local farmers' representatives).

Nardi trenches: trenches to collect run-off water and favor infiltration. These tranches also open the soil and improve accessibility to nutrients for plants. Seeds transported by the wind are retained in trenches and strengthen herbaceous vegetation.

Natural plant-protection products: made of chili, ginger, garlic and sometimes tobacco and caicedra.

Nectar-producing plants planting: plantation of plants that produce nectar to favor pollinators.

Nursery on hot layer and early sowing: seeds are precociously produced on a hot layer nursery (heat resulting from composting). They are then sown directly when temperatures increase.

Off-season crops in bottomlands: cultivation of bottomland plots during drier season.

Organization of grazing paths: collective management, negotiation with farmers on time spent on their fields, organization of water sources.

Organization of meat sector: improvement of collective organization, professionalization.

Participative certification system: certification managed by farmers, support NGOs, processors and consumers (as opposed to certification by a third party).

Participative map making for bottomlands water management: participative determination of where to put hedgerows…etc.

Peasant seed exchange system: groups of farmers produce, exchange and distribute seeds.

Permeable stone dam: at territorial scale, stone dams are installed to slow down run-off water flows and increase sedimentation. It allows cultivation in bottomlands.

Planned grazing: the idea is to mimic wildlife and pastoral herds. Local people combine their animals into one large herd, which grazes one area at a time.

Plantation of Eucalyptus: Eucalyptus trees are planted on top of hills to limit erosion and silting of bottomlands and to produce fire wood.

Pond structures: digging of ponds to store water for animals.

Processing plants: women gather to process fruits from oasis trees.

Production of local adapted seed varieties: production of local seeds adapted to soil and climate conditions by local associations, sometimes with a local research center support.

Promotion of agroecological production modes: promotion of agroecological practices based on crop-livestock integration, by facilitators and peasants.

Protected area: degraded lands are set aside, through periodic rotations, to favor ecosystems' restoration.

Rainfall rice on Tanety: rice cultivation with no irrigation on small plots, with crop rotations including legumes to limit soil fertility loss.

Regulation of animal free movement: limitation of animal free movement to limit their damages on croplands, with hedgerows, fences…etc.

Reforestation: restoring and recreating areas of woodlands.

Reforestation of water source head: plantation of trees near water sources to increase water supply.

Re-vegetation of stone bunds: plantation of endemic plant species on stone bunds, which can be valorized as forage for animals.

Rope pump for vegetable production: introduction of vegetable production thanks to rope pumps installation.

Rotational grazing: pastureland is divided in several plots which are alternatively grazed by animals, to avoid overgrazing.

Sand dams: dams made of sand to collect water.

Seeds coating and dry sowing: seeds coating with clay soil, compost and cereal bran which constitute a humid layer, and dry sowing.

Seeds soaking: submerge seeds in water before sowing.

Shelters for livestock: building of shelters to protect animals from cyclones.

Short food supply chain: farmers process their production and sell it directly to the consumers on farmers markets or fairs for instance.

Shorter-term crops or varieties: choice of varieties with shorter growth period to reduce risk of crop failure.

Short-term rice varieties: rice varieties from research stations, to reduce risk of crop failure.

Soil-improving plants: plants which enhance soil nitrogen, such as legumes.

Solar pumping system: pump running on electricity generated by photovoltaic panels or thermal energy available from collected sunlight.

Stone bund: stones are put along level lines to slow run-off water flow and favor its infiltration.

Storage buildings from local materials: to limit loss of harvested production.

Strengthening of vegetable production: vegetable off-season production thanks to improved access to water.

Sump: kind of temporary well with low depth and narrow diameter traditionally secured with hay and/or wood. It is dug in dry seasons by breeders when natural ponds are dry. It permits to manually water small herds. It is isolated but part of a whole. Animals can therefore move from one sump to another while they are filling.

Supplementation of millet bran: adding millet bran in feed rations to increase protein content and enhance milk production.

System of Rice Intensification (SRI): low input based rice production system. The basic principles are: early transplanting, sufficient distance between plants, compost or manure use, and non-permanent presence of water (to favor roots growth).

Test and diffusion of local seed varieties: seed production by peasant organization

Training in agroecological practices: implementation of an educational farm for production and demonstration (ex: practical training in animal-drawn practices).

Tree nursery for high demand trees: preparation for plantation of trees for food, revenue, forage, wood and hedges.

Urea treatment of hay: improvement of hay digestibility and nitrogen content.

Valorization of crop residues: feeding animals with crop residues.

Water reservoir for vegetable production: digging of pond to increase water storage capacity, with vegetable production around.

Water source networking: improving distribution of wells and drilling sites in pasturelands.

Weir: devices to slow water flow and limit water erosion, in order to favor crop cultivation.

Wind breaks: plantation of trees such as Cajanus cajan to limit wind erosion.

Zai holes: digging of small basins in compacted soils before first rain to retain run-off water. Organic matter is put inside those holes, before plantation of crops inside them.

Appendix 9: List of experts interviewed

Organization	Name
ACF	Bader Mahaman
Agrisud	Sylvain Berton
ARFA	Mathieu Savadogo
AVSF expert associé	Valentin Beauval
AVSF Mali	Marc Chapon
AVSF expert associé	René Billaz
AVSF Togo	Myriam Mackiewicz
AVSF	Stefano Mason
AVSF	Gauthier Ricordeau
AVSF	Katia Roesch
CARE-France	Aurélie Ceinos
CARI	Adeline Derkimba
CARI	Jean-Baptiste Cheneval
CCFD-Terre solidaire	Florian Dejacquelot
ENDA Sénégal	Emmanuel Seck
Etc Terra	Clovis Grinand
GRET	Pierre Ferrand
GRET	Judicaël Fetiveau
GRET Madagascar	Thierry Rabarijaona
IRD	Martial Bernoux
IRD	Damien Raclot
IRD	Benjamin Sultan
RHK	Issiaka Bôh Magassa
Salvaterra	Olivier Bouyer
Tenmiya	Sidi Ahmed Cheine
Terre et humanisme	Pierre-François Prêt
URD	Julie Patinet

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