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RESEARCH ARTICLE

VULNERABILITY EVALUATION OF MILLET AND SORGHUM CROPPING SYSTEM TO CLIMATE CHANGE AND ADOPTION OF NEW TECHNOLOGIES IN MALI

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ABSTRACT

This study analyzes the vulnerability of agricultural cropping systems based on millet and sorghum and the adoption of new technologies in Sahelian and Sudano - Sahelian areas in Mali (West Africa). Semi-structured interviews (ISS) using questionnaires addressed to the chiefs of family farm (FAE) were used for the collection of data. The descriptive statistics and matrices were realized for the data analysis using the following softwares: EXCEL and SPSS20.The results of the surveys conducted in 2014 among 360 farms in Sahelian and Sudano-Sahelian areas, shows that agricultural producers are aware of the main factors affecting the productivity of their cropping system and food security of agricultural holdings. Rainfall variability, characterized by failure and irregularity of rains is the main constraint of cropping systems based on millet and sorghum as stated by 97% of surveyed producers, followed by soil poverty 81%, and the lack of agricultural equipment 47%. The impacts of these factors at the farms level are translated by a decrease in the crops yields and on the frequency of the shortages in foodstuffs which are observed by 98% of the farms every year and more than 50% every 3 years. To reduce vulnerabilities, practices and innovations were adopted by farms as strategies. The main concern fertilizer micro dosing technics, seed soaking, improved varieties, organic and mineral fertilization, soils and water management technics, mechanical sowing, and agro forestry were adopted as strategies.

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INTRODUCTION

Millet and sorghum are important in Food Security strategy, supported by the government of Mali since 2009 trought fertilizer grants (USAID/MSU, 2011). Both crops occupied 67% of total area cultivated in 2010 (FAOSTAT, 2012). In term of production, they are second and third ranked crops after rice. In the total production cereal estimated at 6 674 427 tons in 2014-2015, millet productions of is 1 802 095 tons and sorghum 1 201 397 tones (CPS-SDR, 2015). Considerated as base foodstuff, they are consumed in diversified forms: full grain or transformed in flower for porridge cooking, couscous, bread and alcoholic beverages. However millet and sorghum yields are lower than rice and maize. The annual growth analyzed between 1990/91 et 2008/09 was 1.2 % for millet and 0.8 % for sorghum, while areas were increased in average at 2.1% for millet and 1.3% for sorghum (MSU, 2011). More explanations were mentioned to justified millet and sorghum yield weakness because they are traditional rain fall crops (Kieft *et al.,* 1994, Tyner *et al.,* 2001, in MSU, 2010); their yields are strongly linked to the rainfall, but also to locust attacks and lack of agricultural equipments (Traoré *et al.,* 2002).According to the GIEC (2007), for the climate change, the Sahel is considerate as one of the most vulnerable zones of the world. In fact the previous cycles of drought and rainfall variability affected significantly these regions. The future projections plan for these regions indicated the decrease of the yields of rain fed agriculture of 50 % in 2020, due to a decrease of the cultivable areas and the duration of rainy seasons (GIEC, 2007). This will compromise seriously the agricultural production and population access to food. Adaptation is seen as a fundamental option to limit the negative impacts of climate change on the human, economic and natural systems (GIEC, 2007). The recommended options of adaptation will have to take into account the climatic variability with extreme events as starting point of the process of reduction of the vulnerability in the long-term climate change. They must be consequently focused on current vulnerability and build the future policies base on the recent experience. The necessity of actual vulnerabilities evaluation for the implementation of adaptation strategies becomes an

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opportunity for Mali, towards its agriculture mostly rainfed one. Indeed, 90 % of cultivated areas every year are dedicated to the culture of dry cereal, millet, sorghum, corn and fonio (MA/SAA, 2010). The present study is a contribution of the vulnerability evaluation of the millet and sorghum agricultural cropping systems in the Sahelian and sudano-Sahelian zones of Mali. The general objective is to analyze the vulnerability of the current systems and to identify the technical innovations to reduce vulnerability toward climate change.

MATERIALS AND METHODS

Theories

This section presents the theoretical frame and the methodological approach used for millet and sorghum production systems vulnerability analysis.

Conceptual frame of the vulnerability

The notion of vulnerability was conceptualized in different ways by authors through different approaches. So, two conceptions of the vulnerability were distinguished. The first one, adopted by the researchers of the natural sciences (Brooks, 2003) is focused on the evaluation of impacts of the climate change based on climatic models. In this context, it is defined as "The degree according to which a system may, or shows itself weak, face the fatal effects of climate change, in particular the variability of the climate and the events of extreme climate". The vulnerability depends on the character, on the importance and on the rate of climatic variation, to which a system is exposed, of its sensibility and its capacity of adaptation (IPCC, 2007b). The exposition in the climatic variations is subject to the geographical location (IPCC, 2001). The sensibility is the degree according to which a community is affected by climatic stress. This one can be affected, unfavorably or advantageously, by climatic shocks (IPCC, 2007b). Thus, the sensibility means not only the negative effect, but also includes positive effect, because the presence of climatic shocks can be advantageous to some systems. The capacity of adaptation or "adaptive capacity" is the capacity of communities or households to fit, to reduce their vulnerability to the climatic variability, to moderate the potential damage. It is also the capacity "to make with" the consequences and to get to recover (Smit and Pilifosova, 2003).

The second conception of the vulnerability developed from study in social sciences is focused on people or society, livelihoods, sectors and economy to identify climatic options of adaptation and strategies. In this design, the vulnerability is seen as a characteristic inherent to a society, generated by past and present but not future social and environmental processes (Kelly and Adger, 2000; O' Brien *et al.,* 2004, O'Brien *et al.,* 2004 cited by Lepage *et al.,* 2007). It is defined in this context as the current incapacity of a social system to face phenomena such as the impacts of climate change. This second conception of the vulnerability based on the approach of "the evaluation of the vulnerabilities" which is more and more used to identify the "real" and current vulnerabilities of society (Smith and Pilifosova, 2003). According to this approach, the vulnerability just like the capacity of adaptation can be amplified by certain characteristics (social, economic, political, etc.) of the society and the socioeconomic context and outside this society (Brooks, 2003) which are not considered as being directly bound with the climate (Handmer, 2003, cited by Lepage *et al.,* 2007). There are multiple causes which explain that the populations are incapable to face climate change. The approach of evaluation of the vulnerabilities thus aims at identifying the factors of vulnerability, the possibilities of adaptation and the constraints (O Brien *et al.,* 2004, cited by Lepage *et al.,* 2007). She can also help to identify actions for the strengthening of the impact strength of operating systems (Kelly and Adger, 2000). The evaluations of the vulnerability in this context based generally, on one hand, on the exposure and the sensibility biophysics, and on the other hand, the social sensibility and the capacities of adaptation which allow understanding the vulnerability of the populations.

In this context, the exposure is the nature and the degree to which a system is exposed to a potential risk or to a threat (Locatelli *et al.,* 2010, cited by Devisscher *et al*., 2013). The sensibility refers to the degree to which a system will be allocated by a change such as climatic stress (for example the climate) or the shocks (famine, epidemics). The capacity of adaptation or the "adaptive capacity" is the capacity of communities or households to fit or to reduce their vulnerability to the climatic variability, to minimize the potential damage. Both frames enumerated above give useful learning for the evaluation of the vulnerability through differences in the way of seeing the vulnerability concept and its use. However in spite of their differences, every frame draws the dimensions of the vulnerability in a way and uses them as tools of analysis and evaluation. The elements which concern the analysis of vulnerabilities evaluation are:

Exposure system and units: the system is represented or by the population, communities, the individuals, the natural ecosystems, a branch of industry or a geographical region on which the vulnerability acts (Smith and Pilifosova, 2003; Fussel, 2007).

Dynamic processes: the vulnerability is a dynamic process, changing on inter-temporal and spatial scales.

Multiple threats: a system can be affected by multiple threats, which can include the political, ecological, social, physical and economic change, as well as the technological change and the innovation (RA 2010; Devisscher *et al.,* 2013).

Differentiated exposure: the vulnerability is specific to a system. The systems such communities, individuals are not homogeneous, that is the various households or the individuals of the same community can present different degrees of vulnerability.

Methodological frame of millet and sorghum systems vulnerabilities evaluation

The present study is a microeconomic analysis of millet and sorghum agricultural systems vulnerability in the Sahelian and Sudano-Sahelian areas of Mali. It leans on the approach of evaluation of the vulnerabilities described above. The evaluation of the vulnerability is mainly centered on the current vulnerability, which includes trends analysis of past and present conditions, in connection with the climatic variability and the climatic extremes.

Table1. Regions and research sites characteristics, number of farms

Regions	Research sites	Sites Rainfall (mm)	Agroclimatic zones	Number of farms
Koulikoro	- Nossombougou, - Didiéni, - Koloko	600 – 800 mm	Sudano- sahelian	120
Ségou	- Konobougou, - Niono, - Cinzana	500 – 650 mm	Sahelian and sudano - sahelian	120
Mopti	- Bandiagara, - Bankass, - Koro	500 – 550 mm	Sahelian	120

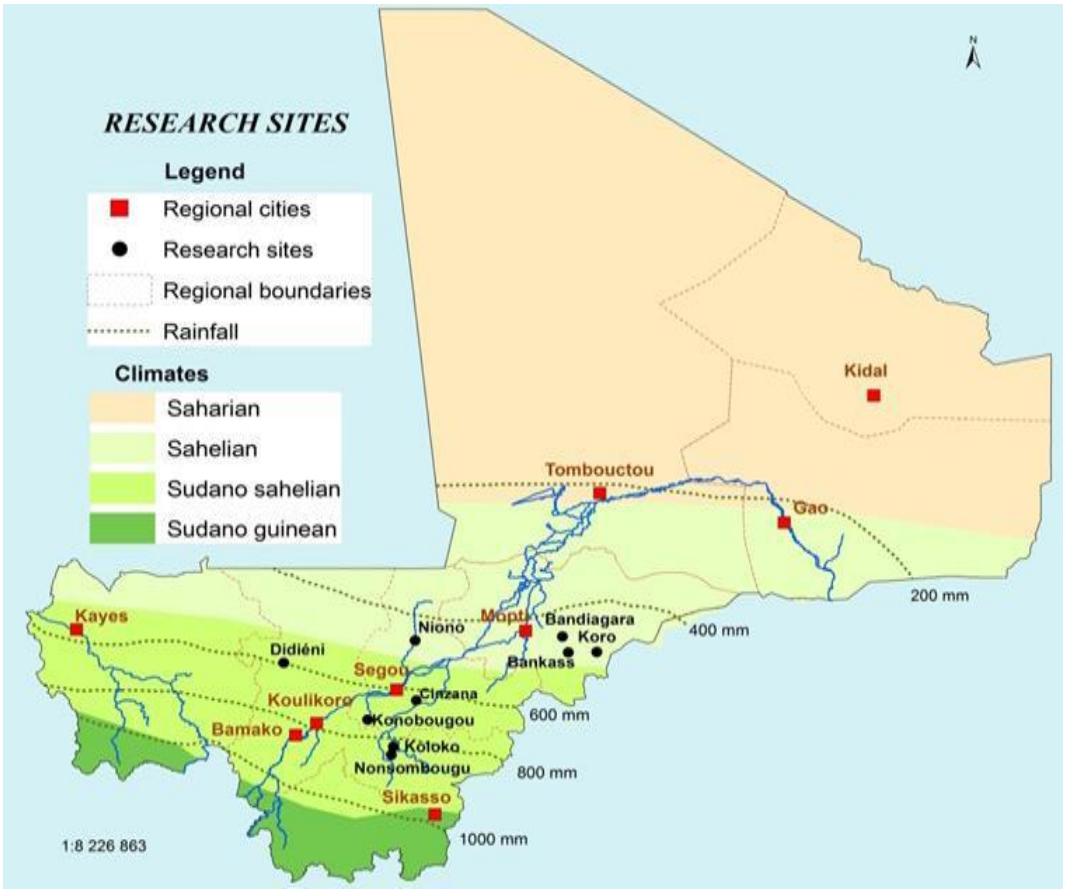


Figure 1. Map of regions and research sites in Mali.

This one is estimated through an analysis of the perceptions of the agricultural producers of the changes and the risks observed during the last thirty (30) years, and the analysis of millet and sorghum production systems constraints. The impacts of the phenomena observed on the productions (yields of millet and sorghum) and the food safety of the farms are also analyzed. These various analyses will allow to identify the main factors which determine the vulnerability of these systems and to determine the strategies of adaptation implemented by the producers for the reduction of the vulnerability. The adaptation in this study is estimated on the basis of the practices or the technical innovations implemented by the producers for the reduction of the vulnerability.

Methods

Zone and sample of study: The zone of study is represented by the Sahelian and sudano-Sahelian zones of the country (Figure1). It covers three (3) administrative regions which represent the main production areas of the millet (Ségou and Mopti) and the sorghum (Koulikoro). Nine (9) sites of research were chosen (three by region), a random sampling of 40 farms by site, 360 farms of total (table1).

Data collection

Surveys were realized in the research sites during 2013 and 2014. The primary data were collected from semi-structured interviews (ISS) using questionnaires which were administered to the farm family chief. They concern the socioeconomic characteristics of farms such as: age, sex, level of education, population size, family workforce, total area, cultivated areas of the farms, the areas for millet and sorghum, the livestock and the equipment of the farms. It concern also the institutional environment of the producers and their organization, the credit system, the collaboration with the technical structures, membership in the groups, climatic variability perceptions and its impacts on millet and sorghum

production system. The secondary data were collected at the technical structures level evolving in regions and sites of study. It's related to the information of biophysics environment, millet and sorghum yields, and the sites rainfall.

Statistical analysis of the data

The descriptive statistics (average, frequency) and cluster analysis were used for the data analysis using EXCEL and SPSS 20.

RESULTS AND DISCUSSIONS

Socioeconomic characteristics of the farms

The sample of the investigated farms chiefs is constituted by 92% of men with the average of 48 years old. The farming constitutes the main activity for 98% of the farms. The main ethnic groups consisted of Bambara (42%) and Dogons (33%). Most of the farmers did not received formal education (87%). However, 33% can read and write (neo-alphabetized), 78% benefit from supervisory research services, agricultural extensions, NGO, 50% have access to the credits and the rural exodus is practiced by 64% of farms.

Vulnerability of systems millet and sorghum in the sites of research

The studied system is the millet and sorghum agricultural system. The analysis concerns the vulnerability of this system and also the farms food safety in the context of variability and climate change risks. The unit of study is the household or farm, the period concerns three decades for the observed for climate changes and 10-15 years for the climatic variability. This is important for understanding the producers' perceptions of the environmental phenomena, the threats and the mechanisms of adaptation of farms. The ladders of analysis concern the month and the year. Semi-structured interviews (ISS) are realized to collect data of perception of the producers. Quantitative data were also collected on the sites of research for comparisons, with the aim of validating the data of perception. These concern the data of rainfall and yields of millet and sorghum.

Perceptions of the producers on the climatic risks observed in the zones of study

The data analysis of perception shows that risks and climatic hazards were observed during thirty (30) last years in the study sites through the droughts, the rainfall variations, the high temperatures, the strong winds and the floods (figure2). According to the perceptions of the producers, the rainfall variability and the droughts are the main climatic factors which affect the systems of production with millet and sorghum. However the rainfall variability is quoted by 97 % as the most important. The data analysis of rainfall of the last four decades (1971-2000) collected in the stations of research sites indicated the rainfall variability through inter annual fluctuations as noted by farmers (figure 3). A general tendency to the rainfall decrease is observed in all the sites between 1971s in 2000, and this one is more pronounced in the Sahelian regions (Segou and Mopti) than Sudano-Sahelian ones, so explaining the correlation between zones vulnerability and rainfall. The rainfall analysis in various localities of Mali over the periods 1951-1970 and 1971-2000 shows important changes. We note a decrease of the quantities of 20 % rains over the last 50 years, between 1951 and 1970 considered as wet and the last reference period 1971-2000 considered as dry. All these changes have move the isohyetes 200 km southward (Traoré *et al.,* 2000; CNRST, 2003; MET, 2009; MAE-AEDD, 2011). Generally speaking, the average pluviometry of 1951-1970 varied between 95,3 mm in the North and 1380,8 mm in the southwest. It oscillated from 1971-2000 between 70.7 mm in the North and 1121.1 mm in the South, that is a reduction in 24,6 mm in the North and 179,2 mm in the South in one ½ century (MET/PANA, 2007). It appears that the most important reductions in the levels of rainfall were observed during the 1971 and 1984 drought period. In Mali, the rainfall variability is cited in the majority of the cases as the main constraint of crops production systems (MAEP, 2004). This constraint is the main factor of yield fluctuations for rainfall crops in the Sahel (Kini, 2007; Ouédraogo, 2010). The data analysis of millet and sorghum yields in regions that cover research sites has been subject to the same fluctuation (decreasing trends) as the rainfall during the last three decades (figures 4-1 and 4-2).

Factors of vulnerability of systems millet and sorghum

The pluviometry variability as perceived by the producers is shown at the level of farms during thirty last years through rains shortage and irregularities. The phenomenon is noticed by the producers in the beginning of the rainy season, the duration of the season, the quantities of rains and in the intensity of rains. The late starting, the short duration, the reduction of quantities and rain intensity which are respectively collected by 80%, 92%, 73% and 77% of the producers are investigated in the research sites. The analysis of the system constraints, based on farmers' perceptions, highlights that various factors affect the productivity of the millet and the sorghum. These concern rain shortage and irregularities (87%), soils poverty (68%), lack of agricultural equipment (60%), weak and/or not using improved varieties (23%), weak and/or not using fertilizers (52%), the attacks of the enemies of cultures such caterpillars (3%), locusts (5%), and birds (1%). Of these cited factors, rain shortage and irregularities are classified by 97% of the producers investigated in the whole of sites as the first risk factor of millet and sorghum yield decrease, followed by the soils poverty (81%), and lack of agricultural equipment (47%). The impacts of these factors were observed at the farms level by crops low productions and yields. The general trend of yield decrease during the last decades is perceived by 94 % of the producers in the sites of Koulikoro for the sorghum that is the main production, and for the millet by 97 % % and 89%, respectively for the sites of Segou and Mopti. These perceptions confirm the tendencies of the yields on these crops noticed in these regions of study (figures 4-1 and 4-2). According to the producers perceptions, the low productions and the yields observed on millet and the sorghum affected the food safety during the last decades. In all sites, only 26 % of farms obtained 12 months food supply in cereals. Indeed, investigated 90 % of the exploitations say they observed the food shortages during the last 10-15 years. The frequencies of these shortages are observed by more than 98 % of the producers every year and around 50 % every 3 years (figure5).

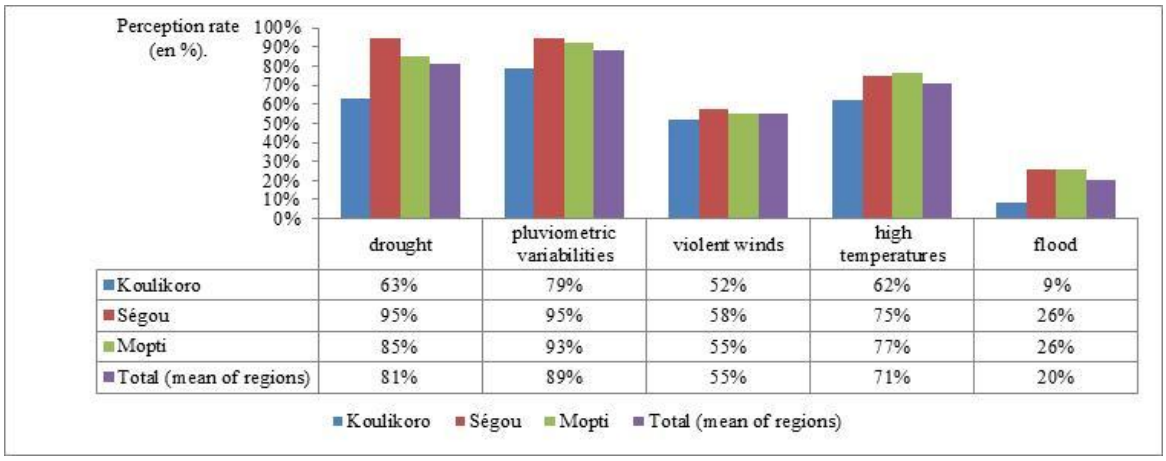


Figure 2. Perceptions of main climatic phenomena observed during the last three decades in the sites of research.

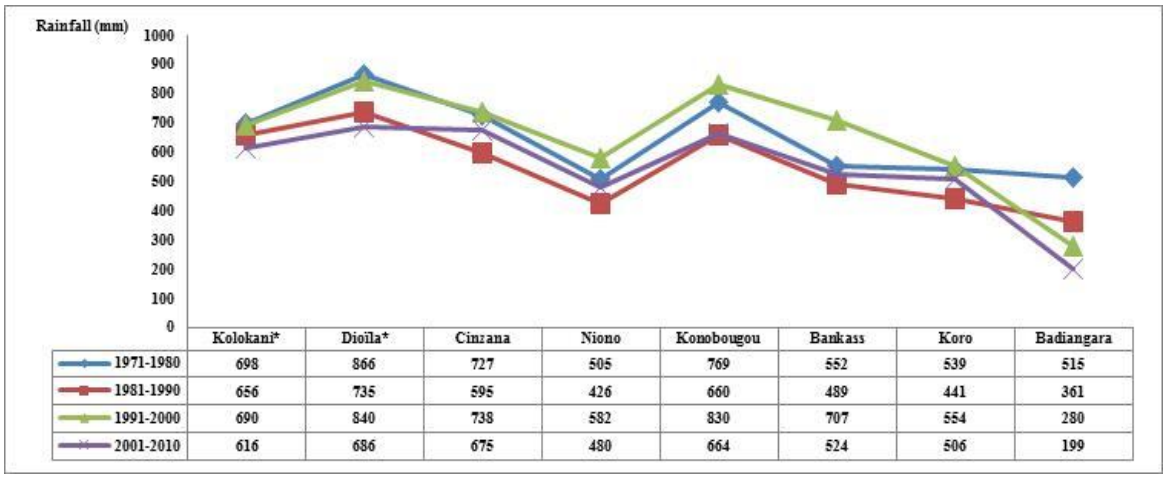
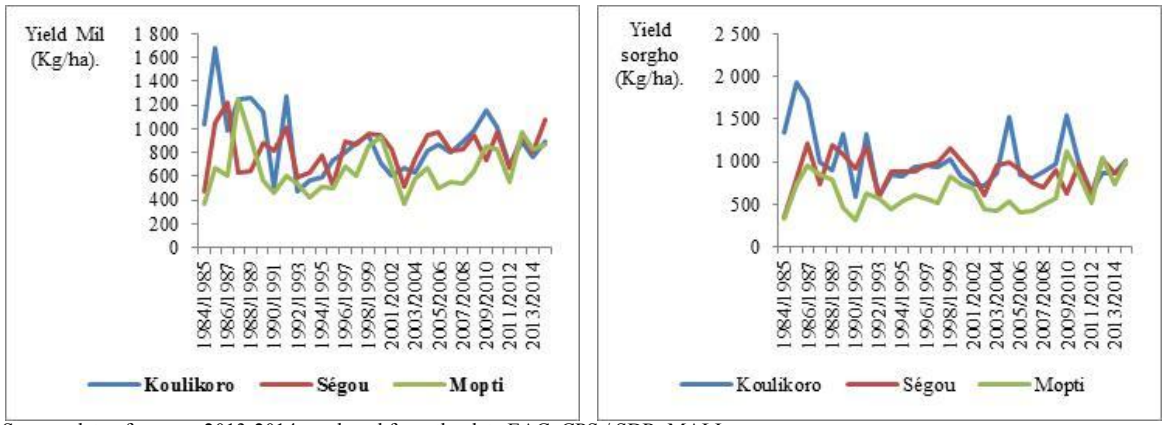


Figure 3. Annual mean rainfall observed in the sites of research from 1971 till 2010



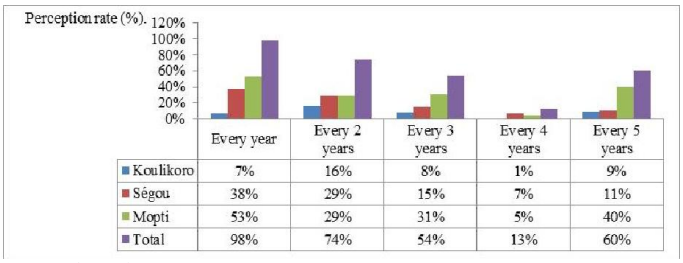
Source: data of survey, 2013-2014, analyzed from the data EAC, CPS / SDR, MALI.

Figures 4-1 and 4-2. Evolution of the yields of millet and sorghum from 1984 till 2015 in the regions of study, 4-1: yield millet and 4-2: yield Sorghum

Adoptions of new practices and innovations at farms level

The vulnerability is defined as the exposure at a risk and a limited capacity to face it. To reduce the risks of vulnerability linked to the agricultural production, strategies were developed by 99% of the farms investigated in all sites of research (figure 6). The main strategies concern the micro dosing fertilizer (76%), the soaking of seeds (39%), the short and medium cycle varieties (49%), application of organic fertilizer (30%), composting (33%), early seeding (26%), the use of stones barriers (14%), plowing billons (16%) and bunds (6%), the mechanical seeding (26%), application of mineral fertilizers (9%),The earthing-up of plants (9%). Other strategies and techniques are also practiced like, crops associations and rotation, zaï, keeping crops residues in fields, planting trees, use of phytosanitary products and respect of the agricultural calendar (activities planning). These practices and the innovations below enumerated are cited in studies carried in the Sahel (Sogoba *et al.,* 2012 ; Sall *et al.,* 2011 ; Amoukou *et al.,* 2007; Terrafrica, 2010, studies Fssa, 2011;

Intercooperation Sahel, 2008; USAID, 2014; Acdi-cilss, 2007; Care, 2010; Devisscher *et al.,* 2013; Tree aid, 2014). They related to adaptation strategies and resilience of agricultural systems of towards climate variabilities and change. The management of the water and soils, crops enemies, the inputs, the improved varieties, the restoration of land cover the plant place setting, the filtering bunds, the vegetative bands, the systems of water harvesting, the cross billons or contour lines, micro-water retention areas, fertilizer microdosing are a part of these strategies.



	Every year	Every 2 years	Every 3 years	Every 4 years	Every 5 years
Koulikoro	7%	16%	8%	1%	9%
Ségou	38%	29%	15%	7%	11%
Mopti	53%	29%	31%	5%	40%
Total	98%	74%	54%	13%	60%

Source: data of survey, 2013-2014

Figure 5. Perceptions of food shortage frequencies observed during the 10- 15 last years in the whole research sites.

Conclusion

The rainfall variability, the soils poverty and the lack of agricultural equipments constitute the main factors of vulnerability of the agricultural systems based on millet and sorghum in Sahelian zones and Sudano-sahelian in Mali. However, the climatic factor, represented by the rainfall variability is perceived as the main factor affecting most the productivity of the systems. This one is shown through rain shortage and irregularities which were observed during the last thirty years. The impacts of these main factors on the systems were translated by low productions and yields decrease, the frequent food shortages, exposing them to more food safety vulnerability. To reduce vulnerabilities, strategies are implemented by the producers. The main strategies concern the microdosing fertilizer, the soaking of seeds, the short and medium cycle varieties, application of organic fertilizer, composting, early seeding, the use of stones barriers, plowing billons and bunds, the mechanical seeding, application of mineral fertilizers, the earthing-up of plants. Other strategies and techniques are also practiced like, crops associations and rotation, zaï, keeping crops residues in fields, planting trees, use of phytosanitary products and respect of the agricultural calendar (activities planning).

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