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Effect of Climate Change and Variability on Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) Production in the Sudanian and Sahelian Agro-Ecological Zones in Mali

By

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CLIMATE CHANGE AND LAND USE

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DECLARATION

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Climate change is expected to increase vulnerability in all agro-ecological zones of Mali through rising temperature and more erratic rainfalls, which will have drastic consequences on food security and economic growth. This study aimed at assessing the effect of Climate Change and Variability on Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) Production in the Sudanian and Sahelian Agro-Ecological Zones in Mali. First, the perception of farmers on climate change variability and their adaptation practices to overcome or reduce the negative impacts of climate change on their farming system as well as their livelihoods were investigated in the Sahelian zone. Therefore, 119 farmers' household including women and youth were randomly selected and interviewed using structured questionnaire. Next, the changes in trends of daily temperature and precipitation extremes in Sotuba and Cinzana during the period 1961 - 2014 were assessed. In order to investigate extreme precipitation and temperature, daily minimum and maximum records for two stations (Ségou and Bamako) were collected at the Aghrymet Meteorological Centre of Niamey for the period 1961-2014. Finally, the performance of two millet varieties in two agro-ecological zones of Mali was assessed using the DSSAT (The decision support system for agro-technology transfer) model under different climate conditions. Two years' experiments were therefore conducted at Agricultural Research Station of Sotuba and Cinzana in the randomised complete block design with 4 replications. The fertiliser treatments included Control, MANURE, NPK and NPK+MANURE. DSSAT model were used to simulate crop grain yields under 2 different weather conditions (historical and future). The results showed that farmers perceived a decrease in annual rainfall as the main factors of climate change and variability. Several strategies such as selling of animals, planting improved crop varieties, engaging in new activities (outside agriculture) and credit were the commonly preferred adaptation strategies to deal with climate change and variability. A significant decrease of warming trends in cool days, cool nights, whereas warm extreme nights, day times and warm spells on the contrary showed positive significant increasing warming throughout the Ségou Region. The results of precipitation extremes for Ségou showed significant decrease in consecutive wet and extremely wet day. The study provided evidence that during the last 53 years, Ségou was particularly affected by warm extremes based on night time indices rather than cold extremes based on day time indices. At Sotuba, the average grain yield was 1293 kg ha^{-1} and 1503 kg ha^{-1} for the years 2013 and 2014, respectively. In Cinzana, the observed average grain yields in 2013 and 2014 were 1390 and 1530 kg ha^{-1}, respectively. The analyses did show significant differences between the varieties and among the fertilizer treatments. Moreover, millet yield responded to the different historical climatic conditions under all treatments. In line with the experimental data, the highest historical grain yields were achieved when the combination NPK+MANURE was applied. Millet grain yields were higher under the simulations with historical weather data than the simulations with climate change scenarios. Simulation of climate change effects on millet grain yield showed that all scenarios underestimated crop yield compared to the Baseline for all treatments and both varieties. Significant differences ($P < 0.05$) were revealed among the scenario outputs. All the varieties showed lowest grain yields under the four treatments for ACCESS1-0 (Hot-Wet) among the scenarios. Based on the findings of this study, policy could be developed to enhance farmers' adaptation strategies in the Sudanian and Sahelian zones of Mali.

DEDICATION

To my father (Aboubacar Boncano Touré) and my mother (Mme Touré Aissatou Traoré), for making me what I am today. They bore me, raised me and supported me in the hardest of times. Also to you, my husband, Idriss Sermé and my twin daughters Habi Amira Idriss and Aissatou Charifa Idriss. To my beloved siblings, Arahamatou, Youssouf and Mariam Aboubacar Touré for prayers and encouragements.

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Halimatou Aboubacar Touré

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AGRHYMET	**:**	Centre for Agriculture Hydrology and Meteorology
ANOVA	**:**	Analysis of Variance
BMBF	**:**	German Federal Ministry of Education and Research
CCI	**:**	Canadian Conservation Institute
CERES	**:**	Crop Environment Resource Synthesis
CH_4	**:**	Methane
CILSS	**:**	Permanent Interstate Committee for Drought Control in the Sahel
CLIVAR	**:**	Climate Variability and Predictability
CO_2	**:**	Carbon dioxide
CRRA	**:**	Regional Agriculture Research Centre
CGCM	**:**	Couplet General Circulation Model
CGIAR	**:**	Consultation Group for International Agricultural Research
DAS	**:**	Days After Sowing
DSSAT	**:**	Decision Support System for Agro-Technological Transfer
ET	**:**	Expert Team
ETCCDI	**:**	Expert Team on Climate Change Detection and Indices
FAO	**:**	Food and Agriculture Organization
GCC	**:**	Global Climate Change
GCM	**:**	General Circulation Model
GHG	**:**	Greenhouse Gases
HADCM	**:**	Hadley Centre Couplet Climate Model
IAPPS	**:**	International Association for Plant Protection Sciences
ICASA	**:**	Independent Communications Authority of South Africa
ICRISAT	**:**	International Crops Research Institute for the Semi-Arid Tropics
IER	**:**	Institute for Rural Economy
IFAD	**:**	International Fund for Agricultural Development
IPCC	**:**	Intergovernmental Panel on Climate Change
IITA	**:**	International Institute of Tropical Agriculture
JCOMM	**:**	Joint Technical Commission for Oceanography and Marine Meteorology

KNUST	**:**	Kwame Nkrumah University of Science and Technology
NASA	**:**	National Aeronautics and Space Administration
NCDC	**:**	National Climatic Data Centre
NOAA	**:**	National Oceanic and Atmospheric Administration
N_2O	**:**	Nitrous oxide
NSIDC	**:**	National Snow and Ice Data Centre
O_3	**:**	Tropospheric ozone
OCDE	**:**	Organisation for Economic Co-operation and Development
RMSE	**:**	Root Means Square Error
SRES	**:**	Special Report on Emissions Scenarios
SSWA	**:**	Sudanian Sahelian Zone West Africa
Tmax	**:**	Maximum Temperature
Tmean	**:**	Mean Temperature
Tmin	**:**	Minimum Temperature
UN	**:**	United Nations
UNCCD	**:**	United Nations Convention on Climate and Desertification
UNFCCC	**:**	United Nations Framework for the Convention of Climate Change
UNEP	**:**	United Nations Environment Programme
UNFCCC	**:**	United Nations Framework for the Convention of Climate Change
USAID	**:**	United States Agency for International Development
WASCAL	**:**	West African Science Service Centre on Climate Change Adapted Land Use
WISARD	**:**	Web Based Information Services for Agricultural Research for Development
WBGU	**:**	German Advisory Council on Global Change
WMO	**:**	World Meteorological Organisation
WRI	**:**	World Resources Institute

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background

Broadly scientists are certain that global climate change (GCC) is mainly due to increasing concentrations of greenhouse gases (GHG) from anthropogenic activities such as deforestation and burning of fossil fuels causing global climate change (GCC) (Mendelsohn and Dinah, 2005; IPCC, 2007; National Research council, 2010). They are also certain that ineluctable global warming will have important impact on the worldwide climate (Intergovernmental Panel for Climate Change [IPCC], 2007). Greenhouse gases greatly affect the earth's temperature, which has resulted in the present earth temperature of 14 ^{o}C (le Treut *et al.,* 2007; Karl and Trenberth, 2003). According to Lu *et al.* (2007), the effect of an increase in global temperature causes a rise in a change in the pattern and amount of precipitation, a more frequent occurrence of extreme weather event including heat waves, heavy rainfall and droughts, species extinction and ocean acidification caused by shifting temperature regimes. However, the climate change system which encloses an important deal of climate fluctuations and natural variability have already contributed to the further warming of the globe of around 0.1 ˚C per decades which for several decades is high (Solomon *et al.,* 2007; Mendelson and Dinah, 2005). Global warming has been projected to accelerate within the 21st century (IPCC, 2007).

According to Clark *et al.* (2002), climate change is like an intricate and interdependent environmental challenge facing the entire world. The two consequences expected of climate are:

- Bio-physical and
- socio-economic

Both are related to this present study. Bio-physical impact includes more frequent and intense storms, rising sea water level, extinction of species, crop failure and worsening drought. Furthermore, it has been observed that changes in precipitation and cloud cover, glaciers, reducing snow cover and melting of polar caps are among the bio-physical impact (United Nations Framework for the Convention of Climate Change [UNFCCC], 2007; Mendelson and Dinah, 2005; UNDP, 2004). The impact of socio-economic development is characterised with bio-physical impact including environmental degradation. A typical example is the linkage of environmental degradation to poverty and food security reduction (Koch *et al.*, 2006; Clark *et al.*, 2002). Those linkages stemmed out of the expectations that climate change will affect water resources and food that are critical for survival across developing countries especially in African countries. The populace of these countries heavily rely on supply system that are dependent on climate variation (Nhemachena and Hassan, 2007; Chipo, 2010).

Global warming is responsible for the rise in the earths atmospheric and ocean temperatures. Increased Earth mean surface temperature has been recorded of 0.8 ˚C since the early 20th century, in 1980 about two-thirds of the increase occurred (National Research Council, 2010). In addition, global average temperature showed a warming of 0.78 ºC (0.72 to 0.85) ºC. Over the period from 1850 to 2012 and recent predictions for the end of the 21st century indicate that global average temperature increase will be between 1.5 ºC and 2 ºC (IPCC, 2013).

Climate change is expected to increase vulnerability in all agro-ecological zones of Mali through rising temperature and more erratic rainfalls, which will have drastic consequences on food security and economic growth (Butt and McCarl, 2006; Dell *et al.,* 2012). Climate change projections from the Hadley Centre Coupled Model (HADCM) and Coupled General Climate Model (CGCM), suggest that by the year 2030, average temperature in Mali may increase by 1 -

2.75 °C and 2 - 4 °C before 2060 (Butt *et al.*, 2005; 2006; Konaté, 2010). The impact of temperature on agriculture is of major significance: A 1 ºC rise is linked to a 2.7 % reduction in growth in agricultural outputs (Dell *et al.,* 2012). The biophysical basis is fairly clear-cut. Temperature affects water availability, evapotranspiration and plant physiology directly. Projections for these agro-ecological zones have indicated that rainfall may increase or decrease (Butt *et al.*, 2005; Kanno *et al.,* 2008). Increases in rainfall may reach 12 to 16 % (Butt *et al*., 2005). Rainfall characteristics are specially affected by these changes in rainfall, the onset and ending of rainy season and the distribution and intensity of rainfall events (Traoré *et al*., 2000; Konaté, 2010). The impact of these changes on rainfall characteristic is 20 - 60 % yield losses for agricultural productions by 2025 (Ben *et al.,* 2002; Butt *et al.,* 2005). Here too, the biophysical basis is fairly clear-cut that rainfall characteristics affect water balance, more specifically water availability, evapotranspiration and plant physiology directly (Dell *et al.*, 2012).

Agriculture remains the main source of employment (60% of the population) and contribute significantly to gross domestic product (GDP) (30%) for countries in the Sudano-Sahelian zone of West Africa (SSWA) (FAO, 2012). Smallholder agricultural production is dominated by rain-fed production of sorghum, maize and millet for food consumption and cotton for the market. Farmers experience low yields resulting in increasing uncertainty about being able to produce the food needed for their families (Breman and Sissoko, 1998; Drechsel *et al*., 2001). Major factors contributing to such uncertainty and low productivity are climate variability, poor soil fertility, poor agricultural management and climate change. In West Africa, soil fertility is inherently low (Bationo and Buerkert, 2001; Giller *et al.*, 2011; Piéri, 1989; Vanlauwe *et al.*, 2010) and represents the main constraint for agricultural development. This situation is heightened by the reduction of cultivation of fragile lands, reduction in fallow lengths, limited use of inorganic fertilizers due to high world market fertilizer prices and limited access to credit (De Graaff *et al.,* 2011; Ehui and Pender, 2005). Also, low availability of organic fertilizers contributes to the decline in soil fertility. Land degradation including both water and wind erosion further impoverishes the soils in this region (Cleaver and Schreiber, 1994).

Significantly, rainfall increases have been observed in northern Europe, the eastern part of South and North America and in northern and central Asia, while a decrease and drying has been observed in the Sahel (IPCC, 2007a), against the background of strong multi-decadal variability in rainfall (Dai and Trenberth, 2004; Le Barbé *et al.,* 2002). In the Sahel region, wet conditions in the 1960s alternated with drier conditions in the 1970s and 1980s. Because of large regional differences, gaps and lack of long term data and spatial coverage, the evidence of changes in rainfall at global scales is complex. IPCC (2013), climate predictions indicate that the contrast in rainfall between dry and wet seasons between wet and dry regions will increase even the projections of rainfall are uncertain for the West African region because of uncertainty in the quantification of potential vegetation-climate links. Different global circulation models do not agree in their predictions of climate change for the region, although results of a number of the models indicate that on average the amount of rainfall in Mali will not change, but that the inter-annual variability of the amount of rainfall will increase. Also the frequency of extreme drought is expected to increase (Traore *et al.*, 2007; Washington and Harrison, 2004).

1.2. Problem Statement

Rainfall is highly variable spatially and in total amount. In Mali, climate change poses its worst impact through interference with food security to the growing population. Climate change impact can clearly be seen in recent climate. Despite the fact that both temperature and rainfall indicates an overall increase over time, it is clear that less rainfall is recorded in warmer years. It can therefore be concluded that temperature increase is likely to result in lower rainfall. Several GCM projections have indicated that it will be a decrease in rainfall as well as an increase in temperature between the year 2040 and 2069. The effects of such changes on agriculture are uncertain. This therefore presents the need for an assessment of crop production responses to climate change to support adaptation strategies and policy formulation development to offset any adverse impacts. Multidisciplinary approaches including the use of models are more suitable since agricultural production involves a number of factors.

Change in rainfall patterns, rainfall variability and temperature are likely to increase the severity of periodic drought and extend dry seasons and thus decrease crop yield in several regions. Agricultural production in the Sahel region is heavily dependent on rainfall for the production of sorghum, millet, and cotton and maize. Farmers experience low yields resulting in increasing uncertainty about being able to produce the food needed for their families (Breman and Sissoko, 1998; Drechsel *et al.*, 2001).

Soil fertility is inherently low in Africa (Giller *et al.*, 2011; Vanlauwe *et al.*, 2010; Bationo and Buerkert, 2001) and represents the main constraint for agricultural development. Moreover, low availability of organic fertilizers contributes to the decline in soil fertility. Land degradation including both water and wind erosion further impoverishes the soils in this region (Cleaver and Schreiber, 1994).

The West African semi-arid tropics are those areas where rainfall intensity limits potential evapotranspiration for two to seven months annually. According to Matlon (1990), the potential increases in sorghum and millet yields exist only in the Sudano-Guinean zone and to an extent in the Sudanian zone. These regions are the most important taking about 70 % of total cereal production (Dendy, 1995). The yield of sorghum and millet may be low under the area's environmental conditions but they are relatively the most dependable. Millet is the main cereal crop in Mali with a production of 1,157,810 t and a production area of about 1,484,190 ha (2005/2006) (Giller *et al.,* 2011). It is grown in all agricultural areas of Mali mainly in Sahelian, Sudanian and northern Guinean zones with planting areas estimated respectively at 38.6 %, 21.1 % and 12 % (Giller *et al.,* 2011; Traoré *et al*., 2000) of the total cultivated area. The choice of crop to maturity is influenced by the onset of rain and agricultural calendar of the farmer. In case of early onset of the rainy season, the relatively long cycle varieties are sown first. In case of late onset of the rainy season, the emphasis is shifted to early maturing varieties. Some of the constraints to millet production include; low yield of available cultivars, inappropriate cycle of the varieties in the erratic climatic conditions, downy mildew, etc.

1.3. Objectives of the Study

1.3.1 Main objective

The main objective of this study was to determine the effect of climate change and variability on Pearl Millet yields in the Sudanian and Sahelian agro-ecological zones of Mali.

1.3.2 Specifics Objectives

1. To evaluate farmers' perceptions on climate variability and adaptation strategies to climate change in Cinzana Commune

2. To assess the trends in extreme precipitation and temperature indices for the Sudanian zone of Sotuba and Sahelian zone of Cinzana and

3. To Model the performance of two millet varieties in two agro-ecological zones of Mali using the DSSAT model under different climate conditions

1.4. Hypothesis and Research Questions

1.4.1 Hypotheses

- Farmers were aware of climate change and developed strategies for adaptation

- Rainfall and temperature extremes study to climate-is related to decisions and adaptation strategies of stakeholders and

- DSSAT model is a performance tool that can simulate millet grain yield in changing historical and future climate conditions for Sahelian and Sudanian zones of Mali.

1.4.2 Research Questions

To able to test the hypotheses, the research answered the following questions:

- What are farmers' perceptions about climate change and how have they been adapting to it?

- How has climate change affected rainfall and temperature extremes in the study areas?

- How will climate change and variability affect pearl millet production under different climatic conditions in Mali?

1.5. Organisation of the Research

This thesis comprises 7 chapters in total. After the introductory chapter (chapter 1), Chapter 2 presents literature review and describes climate change and variability and its impact on agriculture and economic, it also describes the generality of pearl millet and its potential yield in Mali.

Chapter 3 give the general methodology used for carrying out the research. It contains an overview of the study region, a brief description of RClimdex model and DSSAT model.

Chapter 4 covers objective 1 by analysing farmer's perception and their adaptation strategies on climate change in Cinzana commune.

Chapter 5 explores changing trend in the daily temperature and rainfall extremes. It aims at achieving objective 2. It established by analysing 5 indices for temperature and 4 indices for rainfall extremes.

Chapter 6 addresses objective 3, is the central of the thesis. It describes the field data, which formed the bases for DSSAT model modification and evaluation using independent data sets from 2 agro-ecological zones.

Chapter 7 presents general conclusion comprising concluding remarks and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This section presents the climate change and variability context in two components. The first one focuses on the context of climate change in four sub-sections. It also gives some important definitions and clarification of basic terminologies often used for such assessment. According to Braimoh (2004), the concepts and definitions are essential since they facilitate comprehension and exchange among researchers and also improve understanding of research by broad readership. The selected terms are: climate variability and change, vulnerability to climate change adaptation; capacity for adaption to climate change and its effects. The second component trace the emergence of climate change sciences for understanding the context of climate change, since it is important to trace the trajectories of climate to the present time. The third section deals with the debates about the drivers of climate change. Panoplies of factors are cited as driving climate changes, which are crucial to understand the debates about change at a global scale as well as in Africa. This section also clarifies the difference between anthropogenic and natural causes of climate change. Observed and predicted climate changes scenarios are discussed in the fourth section in Africa and in Mali. The chapter presents also the climate change effects on agriculture and the economy at the international level, in Africa and Mali.

2.2. Climate Change in Perspective

2.2.1. Definitions of Terms and their Concepts

a) Climate Change and Variability

According to NSIDC (2010), climate refers to statistical weather information that describes the variation of weather at a given place for 30 years' interval. Weather is also defined as the state of the atmosphere at a given time and places with regard to variables such as moisture, wind velocity, temperature and barometric pressure. Even though the difference between climate variability and climate change has been widely debated, their difference is often based on time and scale. Climate variability is defined as the fluctuations in the climate system over short time scales such as (months, years or decades) whereas climate change refers to changes in climate system over longer periods (3 decades or longer). This distinction was noticed in the definitions given by the IPCC (Waston, 2001), UNFCCC recommended other parameters of distinction between the two concepts (Pielke, 1998; Waston, 2001). UNFCCC (2002), however, presented a different distinction between climate change and climate variability. Climate change in this context is defined as change in climate as a result of direct or indirect human activity which alters global atmospheric composition. Therefore, climate change is in addition to natural climate variability observed over comparable time periods. The IPCC (2001) defines climate change as any change in climate over time, whether due to natural variability or as a result of human activity.

One of the most challenging problems currently facing the world is climate change (O'Brien and Leichenko, 2000; Houghton *et al*., 1990). In the same respect, climate variability refers to the seasonal and yearly fluctuations in the rainfall and temperature patterns between and within regions or countries (O'Brien and Leichenko, 2000). Variability may be caused by natural internal processes within the climate system or to fluctuations in natural external forces and is driven by physical processes of the climate system (Waiswa, 2003). The difference between climate variability and climate change is that climate variability is related to seasonal variations of the climate while climate change operates over 3 decades or longer (Kristie *et al*., 2005).

b) Vulnerability to Climate Change

Vulnerability to climate change has been defined as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability has been indicated to be a function of the magnitude, character and rate of climate variation to which a system is exposed, its adaptive capacity and sensitivity (IPCC 2007; Ekwe *et al.,* 2011). Here the system related to communities, admitting that communities are not equaled, so particular individuals or households within communities may have different degrees of vulnerability. Exposure to climate variation is firstly a function of geography. For instance, coastal communities will be affected highly by cyclones and sea level rise, while communities in semi-arid areas may be most affected by droughts. Sensitivity is the degree to which the communities are affected by climate stresses. For example, a community which depends on rainfed agriculture is much sensitive than where the main livelihood strategy is labour in a mining facility (Ekwe *et al.,* 2011).

c) Adaptive Capacity

IPCC (2001) defined adaptive capacity as the ability of the system to adjust to climate change including extremes to moderate potential damages and climate variability, to take advantage of opportunities or to cope with the consequences. Important climate adaptive resource may include firstly, local understanding of climate risk and conservation skills. Secondly, seed and grain storage facilities, physical irrigation infrastructure and farmer-based organisations and finally, diversified income sources, natural water sources and productive land (Ekwe *et al.,* 2011).

Adaptive capacity can vary over time depending on the variation of the conditions, and may change in relation to specific hazards (Ekwe *et al.*, 2011). It is noticed that people in the poorest countries are also less resilient to the effects of climate change due to the fact that they have limited access to those resources that would facilitate adaptation (Ekwe *et al.,* 2011). For example, women are often most vulnerable to the effect of climate change because of their responsibilities in the household and lack of information, resources and services.

d) Adaptation to Climate Change

This is defined as adaptation, and adjustment in natural or human system in response to actual or expected climatic stimuli or their impact which moderates harm or exploits beneficial opportunities (IPCC, 2007a). To reduce climate vulnerability, it is important to focus on building adaptive capacity, mostly for the less resilient people, and in some cases on reducing exposure or sensitivity to climate effects (Ekwe *et al.*, 2011). It must ensure that development initiative do not unintentionally make local population more vulnerable.

2.2.2 Climate Change Science

a) Climate Change Science Historically

The changes in climate was notified by scientists as early as the 1800s (Chipo, 2010). For more than a century, scientists recognized the sensitivity of the world climate to greenhouse gases in the atmosphere (Fleming, 1998; Weart, 2003). Furthermore, some scientists reported that greenhouse gases such as CO_2 and methane (CH_4) play significant roles in increasing the world's temperature (Fleming, 1998). Other scientists indicated that the use of fossil fuels were likely to cause global warming. Arrhenius in (1896) predicted that an increase or decrease in 40% of CO_2 concentration in the atmosphere might trigger glacial advances. This assertion was confirmed by IPCC (2007). A remarkable increase in CO_2 concentration and temperature in the atmosphere was observed in the 1900s (Callender, 1938), however, variation in temperature in the past has shown abnormal temperature increase in the past 50 years than the natural temperature variation in 1000 years (Callender, 1938; Chiotti and Johnson, 1995; Ohshita, 2007).

IPCC over the last decades has investigated in concluding the fact that climate change and global warming are most often caused by anthropogenic factors. This study was done through climate review involving national government and climate experts (Ohshita, 2007). IPCC concluded in their second and third report in 1995 and 2001 respectively that evidence so far indicate human activity have a great impact on climate change. IPCC (2007) in their fourth report again, stressed that greenhouse gases emitted through human activities is responsible for global warming. Furthermore, scope and magnitude of present climate risks are well known and actions urgently needed (Adger *et al.*, 2003).

b) Causes of Climate Change Debates

There is a significant debate concerning the cause of climate change, whether it is induced by human activities or simply with the range of natural variability. Therefore, there is agreement on the causes of climate change and a general opinion about future climate and the potential implications for agriculture (Chiotti and Johnson, 1995). Nonetheless, IPCC's usage of climate change refers to any variations in climate over time, whether caused by variability of nature or as a result of anthropogenic activities. This usage is different from that of UNFCCC where climate change addresses a change of climate that is attributed indirectly or directly to anthropogenic activity that alters the composition of the global atmospheric and that is in addition to natural climate variability observed over comparable time period (Boko *et al.*, 2007). Therefore, what is of importance is that in spite of the factors driving climate, both UNFCCC and IPCC concur there have been noticeable changes in the global climate over the last five decades (Chipo, 2010).

c) Natural Causes

Heat storage in the atmosphere that causes climate change have been found out to be the natural cause of climate change. There has been natural accumulation of greenhouse gases in the atmosphere throughout the earth's history which is also responsible for climate change. Some of the natural activities that have caused greenhouse gas emission are stratospheric aerosols and volcanic eruptions most of which occurred from 1880 to 1991 (Chipo, 2010). The amount of heat changes from the sun and how heat is stored in the oceans also contribute to climate changes.

d) Human Induced Causes

Many studies agree that climate change is slowly occurs the atmosphere which caused indirectly and directly by various human activities with natural climate variability over time. Nonetheless many researchers have come to the conclusion that climate change is mostly as a result of human activities (IPCC, 2000; 2007; Sutton, 2007). The contribution of greenhouse gases in the atmosphere by human activities is through removal of natural sinks such as forests or introduction of harmful gases into the atmosphere, through burning of wood and the use of fossil fuels and other activities.

The key greenhouse gases generated as a result of human activities include CO_2, CH_4, nitrous oxide (N_2O) and tropospheric ozone (O_3). Carbon dioxide has been identified as the major greenhouse gas produced from human activities and it has the highest impact on climate change (Chipo, 2010). The largest growth in greenhouse emissions has been recorded between 1970 and 2014 which is caused by various human activities (Chipo, 2010). 270 billion of CO_2 has been released into the atmosphere since the start of the industrial revolution around 1750 (Chipo, 2010; IPCC, 2007; Marland *et al.*, 2000).

2.2.3 Observation and Prediction of Climate Change

a) Climate Change in Africa

In Africa, the warming of temperature is estimated approximately at 0.7 ˚C in the 20^{th} century (Chipo, 2010). For example, in Africa in the tropical forests over ten year periods, there has been warming rate of 0.29 ˚C (Malhi and Wright, 2004) and in South Africa, 0.1 ˚C to 0.3 ˚C (Kruger and Shongwe, 2004). Africa is expected to rise in mean temperature ranging from 0.2 to 0.5 ˚C and inconsistent rainfall patterns (Hulme, 1996). This warming is more important in the interior of semi-arid margins of the Sahara and central southern Africa (IPCC, 2001). However, that a decrease in temperature was observed from weather station located near to the coast or to major inland lakes in Eastern Africa was observed (King'uyu *et al.*, 2000). This implies that climate changes vary by location rather than ranking blanketing changes as being the same over the continent (Chipo, 2010). For example, there may be a global increase in average temperature, but these global warming impacts vary at the lower scale, by region and country (Chipo, 2010). Observations in Western Africa on the one hand, indicate there has been climate change in the form of a decrease in mean annual precipitation since the end of the 1960s (Chipo, 2010). For example, between 1931 and 1960 and 1968 and 1990, a decrease of 30 to 40 % was observed (Nicholson *et al.*, 2000; Dai and Trenberth, 2004). In the same way, in West Africa, there was a decrease in annual rainfall mean in the tropical rain forest zone of 4 %, 3 % in North Congo and 2 % in South Congo for the period from 1960 to 1999 (Malhi and Wright, 2004). On in the other hand, there has been an important increase in rainfall along Guinean Coast in the last 30 years (Chipo, 2010). Climate change impact with respect to temperature variation and inconsistent rainfall patterns just like most parts of Africa is similar to the situation in Mali. The impact of these challenges on farming activities is expected to be felt hard in these parts of the region owing to its geographical location.

2.2.4 Impact of Climate Change

Many studies have been carried out to give a better understanding of interwoven and complex sphere of climate change, and there is lack of information on the understanding of effect of climate change (Wheaton, 1994). In addition, there are knowledge gaps with regards to impact analysis despite a growing interest in the community of scholars (Tol *et al.*, 2004). At the local scale, impact knowledge is considered to be incomplete and uneven.

Analyses of climate change effects in the 1970s tended to be upon the impact approach, in a rather simplistic non-interactive model and one-way which attributed the impacts upon an exposure unit directly and only to variation in climatic conditions (Chiotti and Johnson, 1995). There was a shift in focus in the 1980s as some authors began to agree that climate change effects could be measured and occur throughout society and at various scales (Warrick and Bowden, 1981) and that climate change impact were also controlled by interactions with other factors (Garcia and Escudero,1981). Although a number of studies have been carried out to determine the impact of climate change on global agricultural trade (Reilly *et al.,* 1994; Fischer *et al.*, 1994), neither of these studies considered agricultural interaction with other structural economic change or economic sectors that might influence agricultural production, even with climate change (O'Brien and Leichenko, 2000).

The impact of climate change may be experienced at different levels both negative and positive (Boko *et al.,* 2007) due to two reasons. Firstly, global circulation model project spatial differences in the direction of climate change and magnitude and, secondly, even in a given region experiencing the same characteristics of climate change, the impacts are likely to be different because some sectors, social groups or ecosystems do not have the same resilience to climate change than others (O'Brien and Leichenko, 2000). According to Rosenzweig and Hillel (1995) in the middle and higher latitudes, global warming will increase the length of the potential growing season, leading to earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season.

A study carried out by Seo and Mendelson (2006) revealed that the increase in temperatures is favourable to small farms that keep sheep and goats because of the facility to substitute animals that are heat-tolerant. Inversely, farms are more dependent on species such as cattle, which are very vulnerable to heat. Furthermore, effects or benefits can be identified for some social groups and some regions, but they are expected to decrease as the magnitude of climate change increases. Others identified adverse effects and expected increases in both extent and severity with the degree of climate change (Chipo, 2010)

In addition, in climate change discussion, policy and scientists are reluctant to recognize, address and discuss the existence of both negative and positive impacts, particularly the positive ones, for discussions are seen to be diverse and counter the efforts to gain a global consensus on climate change (Glantz, 1995; Schneider, 1989). For example, climatically the gradual change view of the future assumes that agriculture will keep on thriving and growing seasons will lengthen. North America and Northern Russia and Europe will prosper agriculturally while southern Africa, Europe, and Central and South American will be more affected by the increased heat, dryness, water shortage and reduced production. Global food productions under many typical climate scenarios increase (Schwartz and Randall, 2003). Nevertheless, it is important to engage in a negative and positive discussion on the effect from climate change, based on the assumption that farmers may benefit from the positive aspects and advantages from climate to improve their livelihoods. Moreover, assessment of climate effects inevitably points to winners and losers and the perception alone of the winning or losing groups can significantly influence climate negotiations (UNEP, 1993; Rosenzweig and Hillel, 1995).

a) Impact of Climate Change on Agriculture Case in Africa

The agricultural sector faces the challenge of increasing production to ensure food security for the projected human population of 2 billion by mid-century without harming the environment and the functioning of its ecosystems (Naab *et al.,* 2012). In the same respect, climate change constitutes an obstacle for stability of production and productivity since Africa is found to be the most vulnerable region to the effects of climate change and variability. Subsistence of smallholder farmers in Africa relying on rainfed farming systems are considered the most sensitive to the impact of climate change (Jarvis *et al.,* 2011).

Agricultural production is affected directly by climate variability since agriculture is linked to climatic parameters and is one of the most sensitive sectors to the risks and climate change impact. At the global scale, any significant change would impact agriculture at the rural scale most (Rosenzweig and Hillel, 1995; Parry *et al.,* 1999). In the past, it may be argued that African farmer have adapted to climate variations and future climate change may force wide region of marginal agriculture to stop producing (Mendelsohn *et al.,* 2000). Climate change impacts on agricultural activities both on economic and physical sectors have been shown to be significant for low input farming systems, such as subsistence farming in poor countries of sub-Saharan Africa that are located in marginal areas and have the lowest capacity to adapt to climate change effects (Rosenzweig and Parry, 1994; Reilly and Schimmelpfennig, 1999; Kates, 2000; McGuigan *et al.*, 2002). Already, thus, Africa is a continent under pressure from climate stresses and is highly sensitive to their impact (Chipo, 2010). Therefore, estimations show that on third of African people already live in drought prone areas and 220 million are exposed to drought yearly (UNFCCC, 2007). IPCC projects that yield from rainfed agriculture in some countries could decrease by the year 2020 and agricultural production and access to food is also projected to be strongly compromised. About 250 million Africans could also face water shortages (Vermuelen *et al*., 2008).

In Africa, agriculture is an important source of food and a prevailing way of life. WRI (1998), stated that an average of 70 % of the population lives by farming and 40 % of all exports are earned from agricultural products. Owing to this fact, economic growth and agriculture must rise in order to realise basic development goals (Chipo, 2010). The most challenge facing Africa is to increase agricultural production and achieve sustainable economic growth as both are important in improving food security. But in Africa, food security is already affected by climate extreme events, especially floods and droughts (Scoones, 1996; Kadomura, 1994).

Africa is projected to be the continent that will be more affected in spite of its least greenhouse gases (Naab *et al.,* 2012). Moreover, in Africa, several studies show a negative impact of climate change on crop productivity (Naab *et al.*, 2012). Future scenarios suggest that among the main world crops, African sorghum and millet production will witness, by far, the highest growth rate for the 2000 to 2050 period (Nelson and Stathers, 2009). A review of predicted effect on sorghum and pearl millet indicates 10 – 15 % losses that would be statistically significant by 2050 according to Knox *et al.* (2011). In addition, Roudier *et al.* (2011) used a meta database of future crop yields from 16 current studies, to evaluate the potential effect of climate change on yields in West Africa and reported yield changes ranging from -50 % to +90 % with a median yields loss of -11 %. The projected effects were wider in the Sudano-Sahelian countries (-1 18 %) than in the Guinean countries (-13 %) because of the drier and warmer conditions in the former countries (Naab *et al.*, 2012). The scientific evidence leaves little gap for doubt that climate is changing and it will have a significant impact on agriculture. This makes adapting agriculture to climate change and variability an important element of agricultural research and development programmes (Naab *et al.,* 2012).

The IPCC reveals that areas of the Sahara are likely to emerge as the most sensitive to climate change by 2100 with likely agriculture losses of between 2 and 7 % of GDP. Central and Western Africa are projected to have losses ranging from 2 to 4 % and Southern and Northern Africa are expected to lose 0.4 to 1.3 % (Mendelsohn *et al.*, 2000). A study done in South Africa carried out by the University of Pretoria and focusing at the provincial level, found a significant correlation between greater historical temperatures and decreased dryland staple production, and forecast decrease in net crop revenues by as much as 90 % by 2100 and the study found small-scale farmers to be the most affected by the decrease.

b) Impact of Climate Change on Agriculture Case in Mali

Agricultural growth is affected by irregular and low rainfall, fragile and poor soils, as well as generally low productivity caused by the common use of traditional farming techniques (World Bank, 2007). The climate in Mali differs largely at the regional scale. The major productive region is Sikasso in Southern Mali with rainfall ranging from 800 – 1100 mm. Therefore, Malian agriculture receives around 400 – 600 mm of rainfall. Rainfall decreased significantly since 1950 (Olof, 2008). According to Ministère de l’Environnement et de l’Assainissement, (2006), rainfall and agricultural production are strongly related since up to 29 % of the value of GDP is added by agriculture to the economy.

A study on climate change impact on agriculture, temperature was projected to raise 1.7 ˚C with slightly decreased levels of rainfall by 2030 (World Bank, 2006). According to this same study, the main impacts include food insecurity and malnutrition and lower agricultural yields. Impacts will be mostly felt by poor subsistence farmers. Other scholars reveal lower yield of millet, cotton, sorghum and rice (Butt and McCarl, 2006).

Except rice cultivation, agricultural productivity per hectare has been low or even decreasing for main crops such as sorghum, cotton and millet (World Bank, 2006). Agricultural growth outcome has mainly been achieved by increase of agricultural land, including marginal lands, reaching close to 7 % per year in southern parts of the country and thus leading to deterioration of ecosystems (Ministère de l'Environnement et de l'Assainissement, 2006). In southern Mali, the annual nutrient losses of soils have been rated to be equal to 40 % of incomes of farmers, (Van der Pol and Traore, 1993). Agricultural land has been lost being as much as 7 – 15 % to land degradation (PNUD, 2006).

In addition, predicted change in temperature and rainfall are likely to impact negatively on crop yield in both wetter and drier areas, since food production in wetter areas will primarily be impacted by the rising temperatures while changes in rainfall have wider impact in arid areas (World Bank, 2013a). An exhaustive literature reviews reveals that the median decline in crop yield in the Sahel caused by climate change is -18 % although predictions include wide differences (Roudier *et al.,* 2011). In the same respect, a study on Mali found that without adaptation the percentage of people found to be at risk of hunger rises from 34 to 64 – 72 % and the economic losses are estimated to be in the order of 1 % of GDP (Butt and McCarl, 2006).

c) Impact of Climate Change on Economies Case in Africa

Agriculture is crucial in supporting rural livelihoods and economic growth over most of Africa. Agriculture is the backbone of major African economies employing between 60- 90 % of the total labour force and accounting for as much as 35 – 34 % of the total export earnings (UNEP, 2006). Regarding developing states, Africa counts the least and poorest developed nations of the world. But in Africa, even though some countries have been making good socio-economic progress but 41.1 % of the population earn less than $1 per day, as compared to the situation in Southern Asia and respectively with 29. 5 %, and 9.9 % in Eastern Asia (UN, 2007). Furthermore, Africa is the one continent in the world where per capita food production has been decreasing or stagnant at a level that is less than adequate (Scholes and Biggs, 2004). In the past 2 – 3 decades in sub-Saharan Africa land, degradation has relentlessly continued with 10 % of the major productive regions visibly affected as noticed from space (Vlek *et al.,* 2010). Nevertheless, Africa loses the equivalent of $ 4billion per year because of nutrient mining (Naab *et al.,* 2012), and another $42billion is lost in income and 6 million hectares of productive land is threatened each year caused by land degradation (Naab *et al.,* 2012).

Therefore, climate change impacts on the economy are far reaching and studies focusing on economic impacts of climate change in Africa are generally correlated to the performance of agriculture (De Wit, 2006; Calzadilla *et al.,* 2009). For most sub-Saharan African economies, agriculture is crucial in supporting between 70 % and 80 % of employment accounting for 30 % of GDP and at least 40 % of exports (Chipo, 2010). Whereas Asia experienced a rapid increase in food production and yield during the green revolution in the late 1970s and early 1980s, in sub-Saharan Africa per capita food production and yield have stalled (Calzadilla *et al.,* 2009). According to many authors, in Sub-Saharan Africa this represent a cause for concern because 62

% of the population live in rural communities and depend mainly on agriculture. Local poverty accounts for 90 % of the total poverty in the region and approximately 80 % of the poor still rely on agricultural of farm labour for their livelihoods (FAO, 2005). National governments often struggle to furnish information on food security during times of crisis (Ayalew, 1997). For instance, Dilley and Heyman (1995) stated that, for international and national agencies, the cost of climatic hazards may result in a shift in expenditure from dealing sensitively to simply dealing with immediate threats. However, irrigation development and improvements in agricultural productivity are major variables not only for future economic development, food security and poverty reduction in Sub-Saharan Africa, but also for climate change adaptation (FAO, 2008).

d) Impact of Climate Change on the Economy Case in Mali

Renewable natural resources and non-renewable natural resources of Mali play a crucial role for development as fisheries; livestock and agriculture which employ 80 % of the population (République du Mali, 2009). However, lower agricultural and forest productivity is caused by forest and land degradation and health cost linked with polluted water and to a lesser extent air pollution (République du Mali, 2009). These costs are mostly borne by sensitive groups that depend on rainfed agriculture and lack access to clean sanitation and water. Local agricultural growth is recognised as important for the decrease of poverty and food security (République du Mali, 2009). Growing rural agriculture is critical for poverty reduction and food security. In the medium term, loss of vegetation covers and land degradation is a main obstacle for Mali's ambition to be an agro-industrial power (République du Mali, 2009). The economy has been growing at around 5 % between 1996 and 2012 (Staatz *et al.*, 2011). It is first and foremost caused by growth in the primary sector, food crops other than rice and to a lesser extent livestock that have been the motor of the Mali's economy in recent years (Olof and Cesar, 2013). The economy is projected to return toward a growth rate of around 5 % by 2013 but the uncertain economic crisis and political situation constitutes a significant risk for economic and social development (World Bank, 2013b).

Agriculture including fisheries, cropping, forestry and livestock was found to account for around 37 % of GDP in 2012, while services and industry contributed 23 % and 40 % respectively (Olof and Cesar, 2013). With the exception of 2012, the long term trend is a decrease in agricultural share of economy caused by a rise in gold production, demographic shift toward urban areas and the normal structural transformation of the economy toward services and manufacturing (Olof and César, 2013). Although, investments increased in irrigation has somewhat decreased the sensitivity to rainfall changes as the link between agricultural production and economic development and rainfall remain very strong (IMF, 2006).

The growth in agricultural, forestry and livestock system has important potential in Mali. Local land is estimated at around 47 million hectares including 30 million hectares of grazing land, 12 million hectares of arable land, 3.3 million hectares of wildlife reserves and 1.1 million hectares of forestry reserves. For irrigation, 2.2 million hectares are favourable and the country has no negligible water resources (Djiré *et al.,* 2013), while only 12 % of the countries large irrigation capacity has been currently used (IFAD, 2011).

It has been observed that the rise in yields per hectare in millet and sorghum remain very low; the average yearly growth rate of yield per hectare of main food crops is 2.5 % which can be compared to a population growth of 3.6 % per year (Olof and Cesar, 2013). Also, it should be noted that this masks the wide gaps between low potential and high potential farming land and various yields for different farm sizes (Olof and Cesar, 2013). For instance, production of cereal per capita is often three times higher for those with bigger farms compared to those with smaller farms (Staatz *et al*, 2011). About 1 % of GDP represent cotton and 15% for export incomes. Cotton yields per hectare failed to increase between 2001/2002 and 2008/2009 (Olof and Cesar, 2013).

According to the Office du Niger, investment growths have been substantial which contributed to significantly higher yields per hectare. A sharp increase of land and water disputes has also emerged at the Office du Niger (Olof and Cesar, 2013). The investments have occurred in the context of an unclear land tenure system creating wide governance challenges and where legislation to manage environmental and social impacts face significant challenges for implementation (Djiré *et al.*, 2013).

The creation of job through labour intensive public works can be an important way for reversing environmental deterioration and increasing investments in agriculture through plantation of forests, irrigation works and soil and water conservation (Bourdet, 2011).

2.3. Generality on Pearl Millet

2.3.1 Origin, Taxonomy and Geographical Distribution

Pearl millet is scientifically known as *Pennisetum glaucum* (L.) R. Br. It is a yearly, allogamous cross-pollinated and diploidia cereal, belonging to the *Poaceae* family, subfamily *Panicoideae*, tribe *Paniceae*, subtribe *Panicinae*, section *Pennicillaria* and genus *Pennisetum* (Rai *et al.,* 1997). The essential wild relatives of cultivars of pearl millet include the progenitor, *Pennisetum glaucum subsp. Monodii Maire, P. purpureum K. Schumach, P. pendicellatum Trim., P, oriental Rich, P. mezianum Leeke,* and *P.squamulatun Fresen.* Previous were *P. Typhoideum L.C. Rich* and *P. americanum (L.) Leeke.* The four cultivated variety types/ species pearl millet are *typhoides* (generally found in India and Africa), *Nigritarum* (dominant in the eastern Sahel), *globosum* (in the western Sahel) and *leonis* (dominant in the West African coast) (Syngeta Foundation for Sustainable Agriculture, 2006).

Pearl millet was domesticated at the southern some edge of the Sahara 3000-5000 years ago from *Pennisetum violaceum* (Lam.) rich in the Sahel (Andrews and Kumar, 2006). It was used in East Africa and from there to southern Africa and the Indian subcontinent, about 3000 years. It reached the tropical Americas in the eighteenth century, and the United States of America in the nineteenth century. Millet is a common cereal in the semi-arid areas of West Africa and the drier parts of eastern and southern Africa and the Indian subcontinent (Andrews and Kumar, 2006; Oumar *et al.,* 2008).

2.3.2. Morphological Characters

Millet (*Pennisetum glaucum (L.) R. BR*)) is a grass upright to which the stem, spinal cord without shortcomings, reaches a height which varies from 50 to 400 or even 500 cm, depending on the variety (Rachie and Majmoudar, 1980; Diop, 1999). However, in the semi-arid zone, the stem height does not exceed 300 to 380 cm and has a diameter of 1 to 2 cm (Zongo *et al.,* 1988; Amadou, 1994). The root system consists of shallow roots and others that can penetrate up to 200 cm in the soil, which explains the adaptation of this plant to dune soils (Boubacar, 1985; Sivakumar and Salaam, 1994; Alhassane, 2009).

The stem is rigid and has full internodes including those of the base which are the shortest. The nodes bases are able to give primary, secondary and tertiary tillers. Tillers are not all fertile: 1-7 tillers per plant usually fail to produce heads. Leaves alternate sheathing and parallel ridges are inserted on the stem at the nodes. They have a sheath enclosing the shaft and blade lanceolate. The ridges are well developed and prevent the blade to bend. The blade is a holder of stomata on both sides (Denis, 1984). The inflorescence is constituted of an apical panicle very dense and cylindrical in shape. Its length and diameter depend on the variety (15 to 140 cm in length and 0.5 to 4 cm diameter). The panicle (fake head) is formed of a rigid spine bearing spikelet stalked and grouped in clusters. Each spikelet has two flowers: the upper flower is hermaphrodite or female, generally fertile, while the lower flower is sterile or male. In general, there are few days' gap between male and female blooms which promotes cross-fertilization.

The fruit (sub-form of grain) is a caryopsis (globular elliptical) of about 4 mm length and of varying colour (whitish, yellowish or grayish). Seeds of millet are densely distributed on the head (Denis, 1984).

2.3.3. Biological Characteristics

Millet is an annual plant whose growing cycle can be divided into three phases: the vegetative and reproductive and the grain filling stages.

- *Vegetative Phase*

The vegetative phase, which can range from 0 to more than 50 days after sowing (DAS), starts at the seedling emergence and continues until panicle initiation. Germination is hypogenous in millet and occurs about 48 hours after planting if conditions are favourable. The rise vegetative phase take place with the appearance of the first leaf, 4-5 DAS. As the raised ends, the buds of all the leaves have emerged and in early varieties, 6-7 leaves are already developed (Maiti, and Bidinger 1981). The seedling develops its primary root system and forms numerous adventitious roots.

Tillering begins around 15 days and continues for 10 to 20 days for early varieties. It is generally longer for semi-late and late varieties, while remaining linked to the sowing date in sensitive varieties. Tillers belatedly produced generally do not form head; even if they give, they rarely reach maturity. During the active phase of tillering, the size of the plant remains small (rosette plant), since the elongation of inter-nodes is not yet started. During the vegetative phase, biomass accumulation mainly concerns the leaves and roots. It may also concern stems especially in case of early sowing of a photosensitive variety. The initiation of panicle is marked by the elongation of the apical dome and allows entry into the next phase.

- *Reproductive Phase*

The reproductive phase is often observed around the 50^{th} to 75^{th} DAS. It starts with panicle initiation and often marks the beginning of start of bolting, which means the lengthening of the internodes of the stems from the base. Tillers begin the start of bolting in the same way as the main stem, but with a certain time gap. During the reproductive phase, the accumulation of biomass relates stems and panicles, in addition to the roots and leaves. Panicle spikelet develops on which emerging male and female flowers and seeds appear after pollination. Flowering occurs two to three days after the actual appearance of the panicle. Female flowers bloom earlier than males and their appearance is gradually from the top of panicle to the base. Five to six days later, flowering and pollination of panicle are complete (Maiti and Bidinger, 1981).

- *Grain Filling Phase*

This phase begins after pollination of the flowers of main inflorescence, from the 75^{th} DAS in early and semi-late varieties. It can peak before that date in ultra-early varieties and continues until the total maturity of the head (head of the main stem and tillers). During this phase, biomass accumulation mainly concerns caryopses and the leaves and stems of tillers may produce spikes. The biomass accumulation of grains (and grain filling) is often at the expense of older leaves and young non-productive tillers with dry senescence. Leaf senescence continues until the last 2 or 3 leaves to the top of the stem. The cowpea passes through a milky stage, a waxy or glass phase before reaching physiological maturity, about 20 to 25 days after flowering depending on the variety (Maiti and Bidinger, 1981).

2.3.4 Ecology

Millet is an annual herbaceous plant of the semi-arid areas. It is usually grown in areas with rainfall ranging from 200 to 1000 mm spread over 3-5 months, according to agro-ecological zones of the cultivable strip of Mali (Traore et al., 2000). Millet is adapted to the constraints of the Sahel. It has a strong ability to develop physiological mechanisms of tolerance to drought: slow water loss in the upper leaves, maintaining a favourable water level at the right grain filling stage (Winkel and Do, 1992). Less demanding as sorghum, millet is a cereal which is generally suited to light sandy soils and sandy clay. It is drought tolerant and more successful on low fertility level and at relatively high temperature of soils.

2.3.5 Mode of Reproduction

Millet is an annual species, diploid (x = 7, 2n = 2x = 14 chromosomes), sexed, a hermaphrodite, preferably cross-pollinated with a strongly influenced protogenos. Its pollination is an emophilous (Diouf, 2000). The length of the crop cycle from sowing to harvest can vary from 60 days to the earliest varieties to 180 days for later. The photoperiodic varieties behaviour determines the choice of location. The semi-late and late varieties are the most numerous in the Sudano-Sahelian zone. Early forms typically predominate in the Sahelian climatic zone (Clement *et al.,* 1993).

2.3.6 Production and Economic Importance

After rice, wheat, maize and sorghum, pearl millet is the fifth important cereal in the world. It is a largely grown rainfed cereal crop in Africa in the semi-arid regions and in Southern Asia. In other countries, it is grown under intensive cultivation as a forage crop. Pearl millet is primarily grown for grain production on 25 million hectares in the semi-arid and arid tropical region of Africa and Asia (Rai *et al.,* 2007). Millet accounts for half of global millet production with 60 % of the cultivated land in Africa, followed by Asian countries with 35 %. European countries represent 4 % of millet production and only 1 % in the North of America mainly for forage (Chitalu, 2013). Pearl millet is the third major crop in Sub-Saharan Africa, the main producing countries are Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania, and Senegal in West Africa and Sudan and Uganda in the East (Chitalu, 2013). In the Southern Africa because of commercial farming, maize has partially displaced millet cultivation (Basavaraj *et al.,* 2010).

In terms of both area and yield, 9.3 million ha and production of 9.3 million metric tonnes with an average yield of 1044 kg ha^{-1}, India is the largest producer of pearl millet (Chitalu, 2013). The trend in area, production and productivity of pearl millet suggest that area has increased marginally (2 %) and productivity has gone up by 19 % (Yadav, 2011).

Millet is one of the most important crops in Mali, where the economy is mainly based on the primary sector. According to the revised agricultural sector, millet represented 19.7 % of total GDP in 1985, during the agricultural season 1994-1995, millet production has experienced the highest growth rate of about 27 % against 14 % for maize. During the period with other productions falling considerably (DNS, 1995). In Mali, millet and sorghum are cultivated on about 1.5 million hectares (75 % of arable land). Millet production in Mali has evolved as follows: between 1978 and 1981, production of Mali reached 461,000 tonnes, it has increased in 1988 and increased to one million tonnes in 1990, against sorghum production which has remained stable since 1988 between 670,000 and 750,000 tonnes. It has doubled in time since the late 1970s (FAO and ICRISAT, 1997).

Millet is a cereal plant cultivated mainly for its seed which is used primarily (80-90 %) for human consumption in the Sahel (Ben *et al.*, 2002). Beside, millet as food for consumption, its stems and leaves are used for various domestic purposes including construction of hut, walls, fences and thatches, and the production of mats, baskets, brooms, sunshades, manure and compost and so on. Millet is an energetic, nutritious food, especially prescribed for children and the older persons or convalescents. The grain of millet contains about 10.6 % protein; 5.1 % fat; 66.7 % starch; 1.3 % crude fibre and 1,9 % of mineral elements (ROCAFREMI, 2002). The intake of vitamins from the grains from millet is also appreciable. The grains contain about 0.22 mg vitamin A per 100 g of seeds (Yahaya, 2009).

2.3.7 Adaptation and Agro-Climatological Requirements

Tolerant to dry and hot climates, pearl millet is able to produce reasonable yield on marginal soil where other crop will fail. High salinity and fertility often constitute problems in millet producing areas, however, it performs relatively well on sandy acidic soil conditions, and when available moisture and soil fertility are low (Leisinger and Schmitt, 1995). This adaptation reflects pearl millet origin in the Sahel regions of Africa, where growing conditions are difficult (Myers, 2002). It is tolerant to sub-soils that are acidic (pH 4-5) and high in aluminum content (Oushy, 2010).

The five climatic parameters crucial for pearl millet production are air and soil temperatures, rainfall, and day length (photoperiod), radiation and wind. The effect of these variables is dependent up on the developmental stage of the crop (Felch and Traore, 2010).

Pearl millet development can be widely divided into three growth stages (Begg, 1965):

Growth stage one or sowing to panicle differentiation;

Growth stage two, or panicle initiation to flowering;

Growth stage three, or flowering to grain.

a) Rainfall Requirements for Pearl Millet Growth

Water availability is an important factor for the success of millet in the Sahel (Bley, 1990). Several studies have shown that water shortage in the cycle can reduce or even negate the positive effects of yield growth and thousands of techniques such as the application of nitrogen fertilizers (Donald and Hamblin, 1976; Alhassane *et al*. 2006), tillage (Chopart and Koné, 1994), or the use of improved varieties (Vaksmann *et al.,* 1996). However, the distribution and amount of rainfall are essential factors in determining the ultimate productivity of a crop. A rainfall of 350 mm, well distributed over 75 days at a minimum, can give satisfactory harvest of millet; the efficiency also declines when the rain becomes too much (Yahaya, 2009). The onset of rainy season differs considerably in West Africa, while the end of rain is more defined (Kowal and Kassam, 1975).

During panicle initiation, or the period of the vegetation, the crop is well adapted to water shortage (Mahalakshmi *et al.,* 1988) and can tolerate intermittent breaks in rainfall, which are a common feature of the climate of millet-producing areas. In early flowering and grain filling stages, the crop is most vulnerable to water shortage (Mahalakshmi *et al.,* 1988; Mahalakshmi and Bidinger, 1985). Both the timing of the stress in relation to flowering and intensity of the stress determine the decrease in grain yield (Mahalakshmi *et al.*, 1988). Most of the variation among environment in a multi-location trial was caused by the availability of water during early grain filling.

b) Temperature Requirements for Pearl Millet Growth

Millet demands temperature and is damp cold dread (Yahaya, 2009). Several studies have been carried out over the years on the impacts of air/soil temperature on the germination, growth and yield of pearl millets (Ong, 1983a; 1983b). Pearl millet development begins at a base temperature around 12 ˚C with an optimum temperature ranging from 30 - 35 ˚C and the lethal temperature around 45 ˚C (Felch and Traore, 2010). The temperature base has been found to be fairly stable, regardless of the stage of development. The temperatures in the Sahel are mostly high due to the importance of radiation load and the scarcity of rainfall. Regarding the germination and emergence stage, soil temperature must reach 12 ˚C for germination to begin (Felch and Traore, 2010). The germination rate increases linearly with temperature to a sharply defined optimum of 33 ˚C and then decline sharply as temperatures increase (Ong, 1983c). High temperatures > 45 ˚C and soil surface crusting following sowing may also result in poor crop establishment because of seedling death (Soman *et al.*, 1987).

At the stage of development, the temperature requirements of pearl millet rely on the cultivar. Diop (1999) revealed an optimum range of 22 - 35 ˚C for plant growth and a maximum of 40 - 45 ˚C, the optimum temperature for root elongation is 32 ˚C. A World Meteorological Organization (WMO) (1996) report on the agro meteorology of millet, states that millet requires a temperature between 22 - 36 ˚C for a good photosynthetic response, with an optimum ranging from 31- 35 ˚C.

Cantini (1995) declared that leaf appearance and expansion rate are positively correlated with temperature, and the leaf area index (LAI) increases linearly with temperature in the optimum range. A tiller appears sooner and they form rapidly as temperature rises to about 25 ˚C (Ong, 1983a; Pearson, 1975). Temperatures above 25 ˚C, the time of appearance of the first tiller does not change, there is a decrease in the number of tillers (Ong, 1983b; Begg and Burton, 1971).

Pearson (1975) showed that the rate of leaf production was hastened at high temperatures, it even the number of the leaf primordia on the main stem apex which does not change from 18 ˚C to 30 ˚C (Theodorides and Pearson, 1981). The duration of development phase is very vulnerable to temperatures averaging 18 days in length (McIntyre *et al.,* 1993). Each one degree rise in temperature reduces the length of the period by about two days. There is also no doubt that the number of grain produced is determined during the growth stage two, and the amount of radiation intercepted during this phase is more important than the interception after anthesis (Ong, 1983b). In the stage of reproductive growth, both the rate of the spikelet production and the duration of the early reproductive phase are very vulnerable to soil temperatures since the meristem are at or close to the soil surface (Felch and Traore, 2010). Setting grain is optimum from 22 - 25 ˚C and decline temperatures from above and below this range, whereas grain mass steadily declines with rising temperatures from 19 - 31 ˚C (Ong, 1983b). Plant exposure to prolonged periods of low temperatures < 13 ˚C during the booting stage levels to low grain set (Felch and Traore, 2010). During flowering, high temperatures result in a decrease of pollen viability of florets and pollen grain induced by lower temperatures (Mashingaidze and Muchena, 1982; Fussell *et al.*, 1980)

c) Day Length/Photoperiod for Pearl Millet Growth

Day photoperiod, or length is an important control in the initiation of the reproductive phase of millet in many pearl millet cultivars (Felch and Traore, 2010). Photosensitive cultivar is grown as long season crop, whereas non-photoperiodic cultivars are grown as short – season crops (Syngenta Foundation for Sustainable Agriculture, 2005).

The two main millet growing zones of the world are located in different latitudes, from 11 ˚N to 14 ˚N in western and central Africa and between 25 ˚N and 30 ˚N in north-western India (Felch and Traore, 2010). In these two zones, the length of the growing season ranges from 10 to 18 weeks (Virmani *et al.*, 1982; Kassam and Kowal, 1975). The length of the growing season is inversely related to the latitude and this relationship is more pronounced in West Africa, where season length changes often over a relatively small distance in latitude (Felch and Traore, 2010). However, the photoperiodic roles responses vary in the regions. In West Africa, the onset of the rains is strongly variable, whereas the end of the rains is clearly defined (Kassam and Kowal, 1975). The growth cycle of local millet cultivars changes greatly with sowing date because of photoperiod sensitivity. If sown in May or June, when days are long, the millet plant remains in the vegetative state until day length reaches an inductive threshold (Felch and Traore, 2010). When sown in August or under shorter days on one hand, the duration of the vegetative phase is very short, despite the fact that it is the minimum value that represents the intrinsic earliness of the cultivar (Vaksmann and Traore, 1994). Moreover, Kouressy *et al.* (1998) showed that the number of leaves and the total biomass are greater with early sowing because of the extended development period. However, Bacci *et al.* (1998) indicated that this higher biomass yield is primarily caused by stalks and not to grain yield, in other words, greater biomass does not necessarily mean greater grain yields.

d) Wind Requirements for Pearl Millet Growth

Heavy winds associated with thunderstorms are frequent during the crop season in West Africa. These winds are laden with the particle of dust that decrease visibility and incoming amount and radiation quality; these particles form deposits on the surface of leaf that may influence photosynthesis (WMO, 1996). On the sandy soils in the southern Sahel, wind erosion owing to frequent sandstorms, particularly at the beginning of the rainfall season, is one of the obstacles to crop growth (Michels *et al.*, 1993). If sufficiently buried, these pockets of plant must be replanted. From partially surviving plants covered pockets show delays in development and growth (Felch and Traore, 2010). The maximum leaf number and plant height are lower, with an important decrease in the leaf area index. Grain yield from unaffected pockets is nearly twice that of pockets that are partially covered (Felch and Traore, 2010).

Scholars in northern Nigeria shelterbelt have shown that *Eucalyptus camaldulensis* shelterbelt positively influences yield of millet crops planted close to the belts (Onyewotu *et al.*, 1998). It was shown from experience that the shelterbelt would not have to exceed 100 m apart to fully exploit the protection of the crop from adverted dry and hot air (Felch and Traore, 2010). Differences in substantial yield is as a function of the distance from the belts and could be shown by soil moisture at the sowing and the impacts on crop growth conditions resulting from dry turbulent and heat air generated by the belts (Felch and Traore, 2010). A number of the factors that should be taken into account in the design and development of shelterbelts are described by Stigter (2005). The shelterbelts settled undulation and drifting sand encourages the return of soil protection grasses (Onyewotu *et al.*, 2003).

e) Solar Radiation Needs of Pearl Millet

Millet is a sun-loving plant (which requires direct solar radiation) in which light plays a key role, in both the morphogenetic processed of growth on the determinism of the flowering. Indeed, the length of insolation or photoperiod is a real source of variability in flowering time-sensitive varieties (Alagarswamy *et al.*, 1998; Alhassane, 2009).

The incoming amount of radiation sets the limits for dry matter production. It has two roles in crop production; a segment of total radiation is called photosynthetically active radiation (PAR), which is required for photosynthesis (Felch and Traore, 2010).

Pearl millet is a C4-type plant, meaning it has a high photosynthetic efficiency, especially under high temperature condition, due to the decrease of photorespiration (WMO, 1996). The photosynthesis efficiency depends, on the age of leaves, the degree of their direct exposure to sunlight and genotype (Flech and Traore, 2010). Where direct sunlight is very important both in determining the flowering and in the morphogenetic process of growth of pearl millet. Within the plant cover, the redistribution of solar radiation involves plant architecture, leaf area density, planting density and leaf angle (Bégué, 1991). Several studies have been carried out to determine the radiation use efficiency of pearl millet (Bégué, 1991; McIntyre *et al.*, 1993). The efficiency conversion varies with the stage of development, being highest during tilling and then gradually declining as the crop matures (McIntyre *et al.*, 1993).

2.4 Potential Yields

Potential yields are yield of cultivar when grown in environments it is adapted to, with water non-limiting and nutrients and with diseases, pests, weed and lodging, and other stresses effectively controlled. As such, it is observed from potential yields, which can be defined here as the maximum yield which could be reached by a crop in a given environment, as determined for instance by simulation models with plausible agronomic and physiological assumptions (Evan and Fischer, 1999).

World grain yield records have reached 25 t/ha for maize, 12.5 t/ha for sorghum and 6 t/ha for pearl millet. They were reported in the USA for all three cereals, as well as in India for pearl millet. In West Africa, maximum yields are far below these records. Research stations have typically recorded grain yields of 4 t/ha for sorghum, 6 to 7 t/ha weighted with early caudatum / kafir varieties. For pearl millet, grain yields of 3.2 - 3.5 t/ha have been reported respectively in Nigeria and Mali (Clerget and Traore, 2009).

During 2008, Malian farmers have planted millet (Pearl millet (*Pennisetum glaucum (L.) R. Br.)* on 1,615,450 ha and sorghum (*Sorghum bicolor L. Moench*) on 986,367 ha with respective average yields of 768 kg ha^{-1} and 943 kg ha^{-1} (FAOSTAT, 2008). In the Sahelian zone of Cinzana in Mali, these crops are the main staple crops and yields were lower than their reported potential (Coulibaly, 2010).

2.5. Other Background Information

2.5.1 Diseases, Pests and Weeds

The major deterrents to pearl millet production are downy mildew, *Striga*, smut, ergot and rust, with the first two being far the most important (WMO, 1996; Syngenta Foundation for Sustainable Agriculture, 2005).

Striga is a parasitic weed that originates and has major problems across many countries of Africa and parts of Asia (Felch and Traore, 2010). In Africa, 21 million hectares are said to be infested by *Striga*, leading to an estimated grain loss of 4.2 million tonnes each year (Sauerborn, 1991). It competes with the pearl millet plant for both nutrients and water. Therefore, low rainfall and low soil fertility favour *Striga* infestation, however, it can be partially controlled by pre-treatment of seeds with herbicides that decrease or prevent the germination of the *Striga* seeds (Felch and Traore, 2010).

Downy mildew (*Sclerospora graminicola (Sacc*) is the most important disease risk to the successful cultivation of pearl millet (Web Based Information Service for Agriculture Research for Development (WISARD, 1999), especially in India. 30% of the harvest in India can be lost during years of serious attacks, with losses in individual fields reaching nearly 100 % (CGIAR, 2006). Despite of the fact that pearl millet hybrids often provide better in grain yield than local open pollinated cultivars, the genetically uniform single cross hybrid cultivars presently available in India are more sensitive to epidemic of pearl millet downy mildew (Felch and Traore, 2010).

Smut is a panicle disease which attacks the flowering head of the pearl millet plant. The main source of inoculum is spore balls in the soil from previously infected crop residue and surface contaminated seed used for sowing (Tharkur and King, 1988). Moderate temperatures (25 – 30 ˚C) rather than cool temperatures, high relative humidity > 80 % and long days seem to be suitable for disease development (Thakur, 1990; Kousik *et al.*, 1988).

Rust is a foliar disease. Occurrence of the disease during the seedling stage can result in substantial decrease in grain and fodder yield and quality (Felch and Traore, 2010). High humidity and cooler temperatures favour disease development (Singh and King, 1991). When *rust* appears late in the season, grain yield may not be affected but the plant fodder is used to feed animals after harvesting of grain (Felch and Traore, 2010). The causes of disease are a severe decrease in digestible dry matter yield of forage (Felch and Traore, 2010). Of all the environmental parameters evaluated, only average temperature below 27 ˚C were consistently correlated with the onset of r*ust* epidemics (Panwar and Wilson, 2001).

2.5.2. Insect and Pest

Relatively, pearl millet has few insect pest problems. In the Asian subcontinent, white grubs are the main pest (Rachie and Majumdar, 1980). In West Africa, there is a range of insect pest that destroy the crop, resulting in economic losses; the main ones are the ear head caterpillar (*Raghuva)*, stem borer (*Acigona*), midge (*Geromya penniseti*) and many species of grasshoppers. In West Africa, pests' surveys show that crops are affected by infestation of ear head caterpillars (Felch and Traore, 2010). The number of surviving diapausing pupae emerging from the soil is correlated with soil temperature and moisture at different depths from November to May. Furthermore, there is a close relationship between onset of rain and soil moisture and month of emergence, which are the key factors in diapause termination (Felch and Traore, 2010). Soil moisture content increasing and lower soil temperature in the upper soil layer are linked to earlier termination of diapausing pupae in the soil layer (Nwanze and Sivakumar, 1990).

Rainfall onset time and amount during the crop season is linked to the stem borer population (Nwanze, 1989). There is a need for knowledge of diapausing populations and the relationship between insect pest and rainfall during the season in regions where sporadic outbreaks happen in order for the weather parameter to be related to the population dynamics of the pest (Felch and Traore, 2010).

2.5.3 Drought Tolerance

A major aspect of pearl millet ability to survive under high stress is the deep root penetration. Pearl millet roots can go down up to 180 cm deep, with approximately two thirds of the root system in the top 45 % of the soil zone (Mangat *et al.*, 1999). This root depth penetration can help millet species to exploit soil water more effectively and therefore survive drought stress, in the same time pearl millet root system also have the capability to penetrate through hard clay pans in the soil (Felch and Traore, 2010). Furthermore, the photosynthetic rate is maintained through periods of serious drought (Zegada-lizarazu and Iijima, 2004). Pearl millet has a monocotyledonous behaviour type of root system made of a primary or seminal root, adventitious root from the nodes and the base of the stem, and the crown root from many lower nodes at below the soil surface. These lateral roots develop with four days after the radicle comes out and helps in the first establishment of the seedling. The seminal root is active up to 45- 60 days, after which it starts to degrade (Felch and Traore, 2010).

Concerning the structure of leaf, stomata are seen on both leaf surfaces. The colour of the leaves is vary from light green to yellow to deep purple. The maximum leaf area occurs at the time of 50 % flowering, when the majority of the tillers have produced leaves. After flowering, there is a decrease in leaf area and at the same time the leaves beginning senescing (Felch and Traore, 2010).

Physiological maturity only on the upper 3 – 4 leaves can be green on the main stem (Mangat *et al.,* 1999).

Stomatal sensitivity to evaporative demand is dependent upon leaf area and age of the crop (Felch and Traore, 2010). This means that the degree to which water use is controlled by stomata and leaf area is influenced by the way ontogeny has to optimize the growth of water use (Winkel *et al.*, 2001). The conception is that millet does not tend to keep moisture but rather transpire freely as long as the root system is able to provide the water needed (Wallace *et al.*, 1993).

2.6. Gaps in Knowledge

From the literature research, the following gaps in knowledge were found that there is lack of scientific information on farmers' perception of climate change and variability in Cinzana. In addition, in Mali, limited knowledge relating to rainfall and temperature extremes study for climate related to decisions making. And, there is very little literature on the validation work of the DSSAT Model on Pearl millet potential yield in the Sudanian and Sahelian zone of Mali using long term scenarios (30 years).

The gaps were tatted by extracting farmers' perceptions of climate change using questionnaires, assessing rainfall and temperature trends to compare with farmers' perceptions, modelling effect of climate change and variability for millet grain yield with DSSAT crop model in tandem with field experimentation millet performance under historical climatic data and different scenarios from 2040 to 2069.

CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

The present chapter gives details on the study area, an overview of the data used and the methods applied for data gathering and processing as well as the models employed for the assessment of rainfall and temperature changes and assessment on changes in potential yield of millet crop under a scenario of climate change. To achieve the planned objectives, field surveys and field trials were conducted. The experimental trials were conducted during 2013 and 2014 in the rainfall season at Cinzana and Sotuba. The details of all fields work are also described.

3.2. Study Area

The study was performed in two agro-ecological zones of Mali as defined by Traoré *et al*. (2010). The two zones involved in implementing the activities were at:

- Sahelian (Cinzana) and
- Sudanian (Sotuba).

In each agro-ecological zone, sites were basically chosen, on the basis of representativeness and data availability, for implementing the activities. These zones were also, deliberately selected because of their main economic activity. These agro-ecological zones have more than 60 % of the population engaged in agriculture and characterized by a single, relatively long rainy season from April to early July and ending between September and October. Key food staples include millet, sorghum, maize, rice, cowpea and groundnut produced predominantly under smallholder production systems. The agriculture sector is affected negatively by climate variability, including drought, flood, heat waves and other extreme weather events. Consequently, cropping systems are characterized by low production due to erratic rainfall, poor soil fertility and poor crop management.

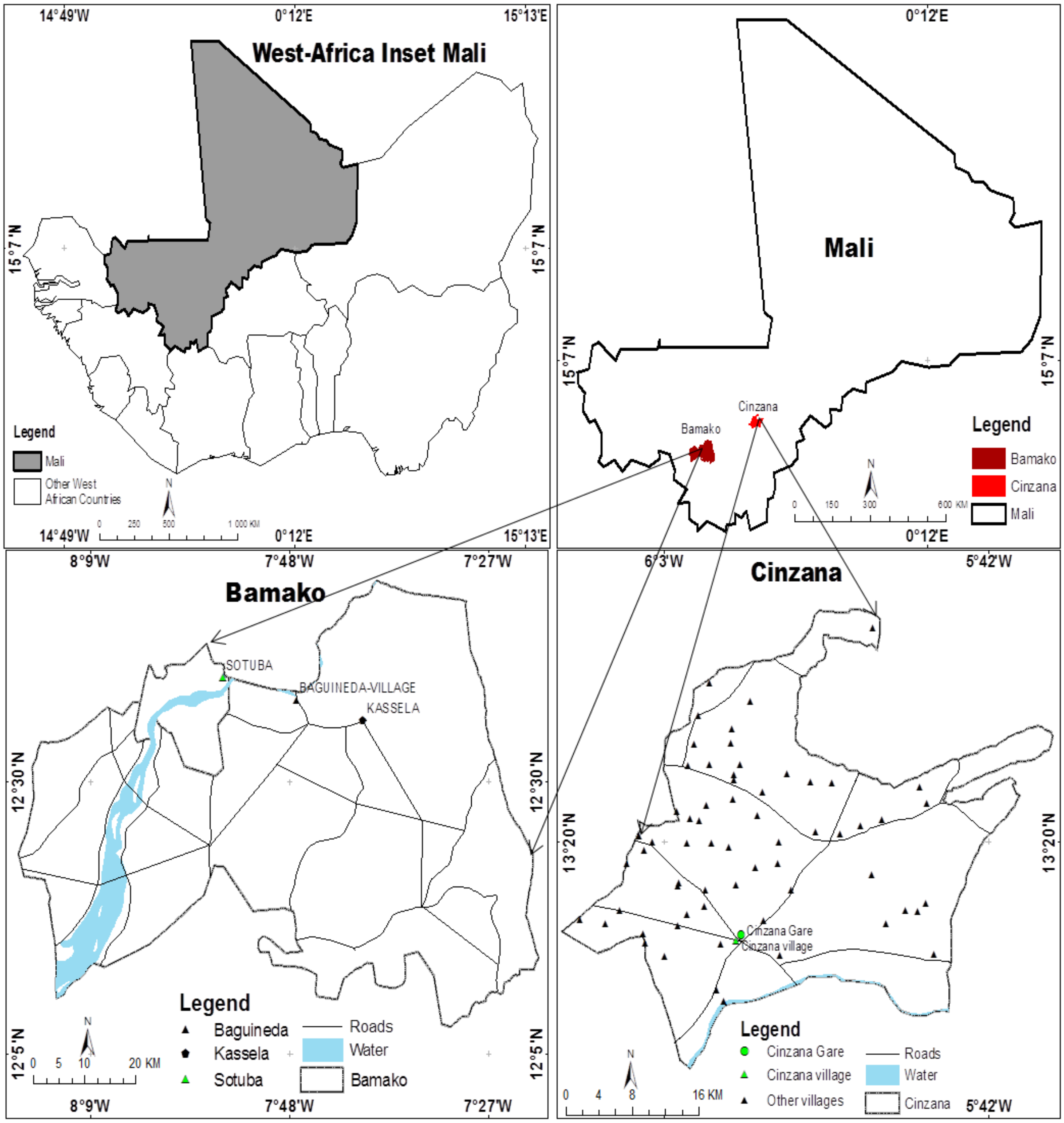


Figure 3. 1 Study Area showing Sotuba (left) and Cinzana(right)

3.3 Cinzana Commune

Cinzana (Figure 3.1) is a village and rural Community in the Region of Segou in the Segou Region of southern-central Mali. Etymologically, Cinzana is the distortion of "Zele and Zan" Zele being women and Zan her husband. The name was assigned to the village of Cinzana by the population coming from Séribougou village (Cinzana Community).

There is a research station situated 5 km from the Cinzana village. Research activities are performed at the Agricultural Research Station de Cinzana (CRRA). It is one of eight (8) major research stations of the Institute of Rural Economy (IER) and reports of the Regional Agricultural Research Centre (CRRA) Niono, one of six regional research centres of IER since its restructuring in 1992. In 1979, the initiative was born of a creation for the benefit of small farmers, a research station focused on the promotion of farming systems based on millet in the Sudano-Sahelian zone. Inaugurated in 1983 and operating to date, the station has devolved and experienced a diversification of its partners, including Ciba-Geigy, USAID, ICRISAT, IFAD, IITA, Netherlands, European Union, SYNGENTA Foundation. Cinzana Gare is located in the rural town of Cinzana 45 km from Segou and 5 km off the national paved road (Axis Segou-Mopti) on longitude 5 ° 57 'West and latitude13 ° 15' North and at an altitude of 280 m.

3.3.1 Physical Characteristics

a) Climate

From a climate perspective, Cinzana Community is situated on latitude 13° 15N and on longitude 5 ° 57 W which makes it a Sahelian zone type semi-arid area. The mean characteristic feature is the change of a long dry season from November to May and a rainy season from June to October. The range annual rainfall of the last ten years is 600 to 700 mm. This amount is unevenly distributed over the period, is insufficient for the needs of cropping which largely justifies the successive years of crop failure. The average temperature ranges between 28 °C and 33 °C with 39 - 40 °C high and thresholds of 8 ° - 12 ° C.

b) Vegetation

Cinzana vegetation is dominated by tree strata, shrubs and grasses. The tree layer includes species rarely reaching 20 m. The species distinguished there are: *Acacia albida, Borassus aethiopium, Tamarindus indica, Bombax costatum, Combretum glutinosum, Pterocarpus lucens, Adansonia digitata, Vitellaria paradoxa* and *Parkia biglobosa.* Among the *Poaceae (Perennial grasses)* are: *Andropogon gayanus, Hyparrhenia dissoluta, Cymbopogon giganteus, Ctenium newtonii* and *Loudetia simplex*. Among the annual grasses are distinguished: *Andropogon pseudapricus, Eragrostis Tremula* and *Ctenium elegans.* The flora is composed of a slightly degraded wooded savannah. The fauna is mostly represented by small species (hares, squirrels, birds).

c) Soil

Kouyate et al., (2014) and Kablan et al., (2008) reported that soil of the area is classified as a leached tropical ferruginous soil with spots and concretions and Alfisols according to Soil Taxonomy (SoilSurvey Staff, 1999), with many Paleustalfs and frequent Plinthustalfs. The Ustalf classification indicates that the soils are, indeed, highly weathered and highly leached. The classification of Plinthustalfs is of special concern because it indicates that the soils contain a plinthite layer of soft Fe and Al oxides that will harden irreversibly into lateritic stone if exposed.

3.4. Sotuba Commune

Regional Agricultural Research Centre (CRRA) at Sotuba (Figure 3.1) is located on the left bank of the Niger River of the Bamako District. It is bounded to the east by the village of Sotuba, to the west by the industrial area south of the Niger River and to the north by the districts of Djélibougou and Boulkassoumbougou. Taking the Bamako District topo-sequence, the Sotuba Agronomic Research Station is located in the lower glacis and on the floodplain of the River Niger, and between two sandstone series.

First, the sandstone series so-called Sotuba is buried under the alluvium of the plains. This emerging in the bed of the River Niger consists of Cambrian sediments located below the first set with a tabular morphology. Along the river ends the perimeter by a water catchment with semi-permanent flooding regime. Second, the sandstone - shale series of Koulouba limit the alluvial plains in the north and comprises several layers of various sandstones intercalated with two beds of shale. These sandstones are overlain by powerful ironstone.

The topography is gently undulating with an average downward slope from north to south ranging from 0.3 to 0.5 %. It is generally flat in the east direction except for the corner -west South -east of the resort where the slopes exceed 0.5%, and the area is highly sensitive to erosion. The existing topography and layout of the station Sotuba allow the development of fields in regular plots.

3.4.1. Physical Characteristics

a) Climate

The station is located in the Sudano-Sahelian zone typically characterized by semi-arid tropical rainfall. The average annual precipitation is about 969 mm. Rainfall mainly occurs between April and October. The wet best periods occur in August and September. During this period the normal is 883.5 mm. The highest rainfall of the station was recorded in 1954 reaching 1,425 mm. The lowest was 591.9 mm in 1996. The frequency of rainfall intensities for short periods is available to the station, and 90 mm / h intensity. The maximum temperature varies between 30 ˚C and 40

˚C during March and April, the minimum temperature varies between 24 and 14 ˚C and occurring between December and January. The humidity varies between 19 and 78 % and is higher during the rainy period. The hours of sunlight vary between 5 and 9 hours per day and are longer during the dry period.

b) Vegetation

Natural vegetation hardly exists in the areas under cultivation. It was destroyed by continuous cultivation and other uses; but fallow exist in the south-western area of the station. Some observation showed *Kaicedra, Vitellaria paradoxa, Thorny, Parkia biglobosa, Fficus Guierra Senegalensis,* and several species of herbs. The density of trees and shrubs varies across the station; the density of trees represents a significant obstacle to the normal course of farming operations. Areas including a high density of mature trees are excluded from the court in search areas, but will be developed for general production goals and grazing as they do not affect normal agricultural activities. Trees located in or around research areas is habitat for birds and shade for experimental crops.

3.5. Perception of Famers on Climate Change/ Variability and their Adaptation

3.5.1. Target Population and Sampling

A study on evaluation of farmers' perceptions of climate change and their adaptation strategies was conducted at Cinzana, a village located in the Sahel zone and Kassela and Baguineda located in South-East in Sudano-sahelian of Mali. A series of on-farm surveys were conducted. One hundred and nineteen farmers' household (119) including women and youth were randomly selected in the villages and were interviewed using structured questionnaires. Information in the structured questionnaire was collected on faming systems, perception on climate change and the concerns for climate change. Data were also collected through a field survey using face to face interviews with farmers. The questionnaire was designed in French and English but interviews were conducted in the local language, *Bambara.*

Interviews were conducted in November 2013. Before being administrated to all the interviewers, the questionnaire was pre tested for is suitability. Precipitation and temperature data were also obtained from the Mali Meteorological station over the period 1961 to 2014. The data gave an overview of the trends of precipitation and temperature and the vulnerability of the region to drought.

3.5.2. Data Analyses

Data from the questionnaire were entered and analysed using the MS Excel and the Statistical Package for Social Sciences (IBM, SPSS version 20) software. Descriptive statistical tools such as, percentages, mean, frequencies and standard deviations were used to summarize and categorize the information gathered. Cross tabulation was used to compare group's means. They were used to identify the differences that prevail between different categories of farmers such as age, gender, level of education and their adaptation strategies. Analysis of correlation was used to determine whether household income rather than education level significantly influenced adaptation strategies to climate variability and change. For the climatic variables analysis, the annual rainfall average was calculated and index of Nicholson (RI) which is a reduced centre variable calculated on annual precipitation to highlight fluctuations in rainfall patterns. It is the ratio of the difference in inter-annual to average standard deviation of annual precipitation amounts. Nicholson indices play a very important role in determining precipitation fluctuations (wet, normal and dry period).

3.6. Assessment of the Trends in Extreme Precipitation and Temperature Indices for Sotuba and Cinzana

Historical daily rainfall and temperature data for Segou and Senou meteorological station were analysed for significant trends. The latitude and longitude of the stations are 12. °53 N and -7. °95 and 13. °40 N and -6. °15 W respectively and the elevations are 320 m and 289 m respectively. The length of historical observation data record available for analyses was 53 years covering the period of 01/01/1960 to 31/12/2014. Climate data were obtained from Tu Tiempo World Weather - locale Weather Forecast at http://en.tutiempo.net/climate and NASA POWER a renewable energy resource web site of global meteorology and surface solar energy climatology from NASA satellite data on 1 by 1-degree resolution (http://power.larc.nasa.gov/common/php/Agro_ExSummary.php).

Extreme temperature indices were computed from minimum and maximum daily and mean, rainfall and temperature indices from daily rainfall data. The data were from the AGRHYMET Regional Centre of Niamey Niger and RClimdex software was used to compute the indices.

3.6.1. Tu Tiempo and NASA POWER data

Tu tiempo data and NASA POWER data were obtained through the World Wide Web, http://en.tutiempo.net/climate http://power.larc.nasa.gov/common/php/Agro_ExSummary.php

Climate variables include in the dataset for each station included mean and daily temperature (minimum and maximum); amount of precipitation; wind speed and visibility; relative humidity and insolation. So far in this study unit, temperature and rainfall was used to fill the gap for time series data obtained at AGRHYMET Regional Centre.

3.6.2 Brief Description of RClimDex

ClimDex was developed by Byron Gleason at the National Climate Data Centre (NCDC) of NOAA, and has been used in CCl/CLIVAR workshops on climate indices from 2001. It is a Microsoft Excel based programme that provides an easy- to use software package for the indices calculation of climate extremes for monitoring and detecting climate change. The objective was to port ClimDex into an environment that does not depend on a special operation system. It is very natural to R as our platform, and it is a free and yet very robust and powerful software for statistical analysis and graphics. It runs under both UNIX and Windows environment. It was discovered in 2003 that the method for computing percentile-based temperature indices in ClimDex and other programme resulted in inhomogeneity in the indices series. A fix to the problem requires a bootstrap procedure that makes it almost impossible to implement in an Excel environment. This has made it more urgent to develop this R based package.

RClimDex (1.0) is designed to provide a user friendly interface to compute indices of climate extremes. It is composed of 27 core indices recommended by CCl/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) as well as some other temperature and precipitation indices with user defined thresholds. The 27 core indices (Table 3.1) include almost all indices calculated by RClimDex (Version 1.3). This version of ClimDex has been developed under R 1.84 and should be run with R 1.84 or a later version.

The main objective of constructing climate extremes indices is to use them for climate change monitoring and detection studies which require the homogeneity of the indices. Data homogenization has been planned but is not implemented in this release. Present RClimDex only includes a simple data quality controlled before the indices can be computed, this users' manual provides step-by-step instructions on

- the installation of R and setting up the user environment,
- quality control of daily climate data,
- calculation of the 27 core indices.

Climate indices details computed and analysed for presence or absence of trends and seasons considered in this study are explained in Chapter 5.

3.7. Assessment of The Changes on Yields of Millet Crop under Different Scenarios of Climate Change Using DSSAT Model

3.7.1. Experimental Design and Treatments

Two varieties of millet were planted with all cultivation practices in two agro ecological zones of Mali; Sotuba in the Sudanian zone and Cinzana in the Sahelian zone. Latitude and longitude for Sotuba are latitude 12° 39 N and longitude 07° 56 W Cinzana commune is situated on latitude 13° 15N and on longitude 5 ° 57 W. Daily records of weather parameters like temperature (maximum and minimum) and rainfall amount were collected from each station respectively.

The experiments were fully rainfed. Trials were thinned to two plants per stand by using hand pull up to 14 days after sowing (DAS). At 21 days (DAS), the first weeding was done by the use of hoe thereafter weeding was carried out at two week intervals until the plant reached the flowering stage. Four soil nutrients amendment applications were used with control which had no application, organic manure (OM), NPK and combination of NPK and OM. Phenological data from the time the millet was planted to harvesting were obtained in the following order. Date of planting, date of emergence (50%), dates of maturity, date of harvest. Yield and yield parameters were taken: number of panicles per plot at harvest, panicle weight per plot at harvest, straw weight at harvest, 1000 grain weight per variety and grain weight per plot at harvest.

The experimental design and treatments are described in detail in Chapter 6.

3.7.2. Brief Description of Crop Model 'DSSAT'

Decision Support System for Agro Technology Transfer (DSSAT) is a software package that integrates the effect of crop phenotype, soil, weather, and crop management system through a database system and allows users to simulate experiments on desktop computers in a minute, which would take significant quantity of time to conduct. DSSAT enables the user to study the "what if" results of different management options and strategies through its different independent programmes that operate together (Jones *et al.,* 2003). These programmes include crop sub modules and databases that describe weather, soil, experimental conditions and measurements, and genotype information (Figure 3.2). The software also enables users to prepare inputs for each of the programmes and compare simulation results with observation, giving users confidence in the models or determine possible modification to achieve improved accuracy. In addition, DSSAT programmes allow users to assess risks associated with different crop production strategies through its multi-year simulation option. Conversely, DSSAT also has a built-in function to specify changes in weather variables without directly modifying the original weather file which suits it for climate change impact studies. In recent updates of the software, it can also directly read historical atmospheric carbon dioxide data from Mauna Loa, Hawaii (Hoogenboom *et al*., 2010).

DSSAT was developed through collaboration between scientist and researchers of different institutions such as University of Florida, University of Georgia, University of Hawaii, University of Guelph, International Centre for Soil Fertility and Agricultural Development, Iowa State University, and the International Consortium for Agricultural Systems Application (Tsuji et al., 1998; Hoogenboom *et al.,* 2003; Jones *et al.,* 2003). DSSAT consists of different crop models

(Jones *et al.*, 2003) such as CERES-Maize (Jones and Kiniry, 1986) for maize, CERES-Rice (Hoogenboom *et al.*, 1994) for rice, CANEGRO (Hoogenboom *et al.*, 1994) for sugarcane, PNUTGRO (Boote *et al.*, 1986) for peanut, and a model for tomato (Hoogenboom *et al.*, 1994).

Actually, DSSAT crop models have been cited by UNFCC (UNFCC, 2007) as a tool which can be combined or integrated with other tools or methods to evaluate impacts, vulnerability and adaptation to climate change. Details of the simulation in DSSAT (Figure 3.2) computed and analysed for the millet crop are described in Chapter 6.

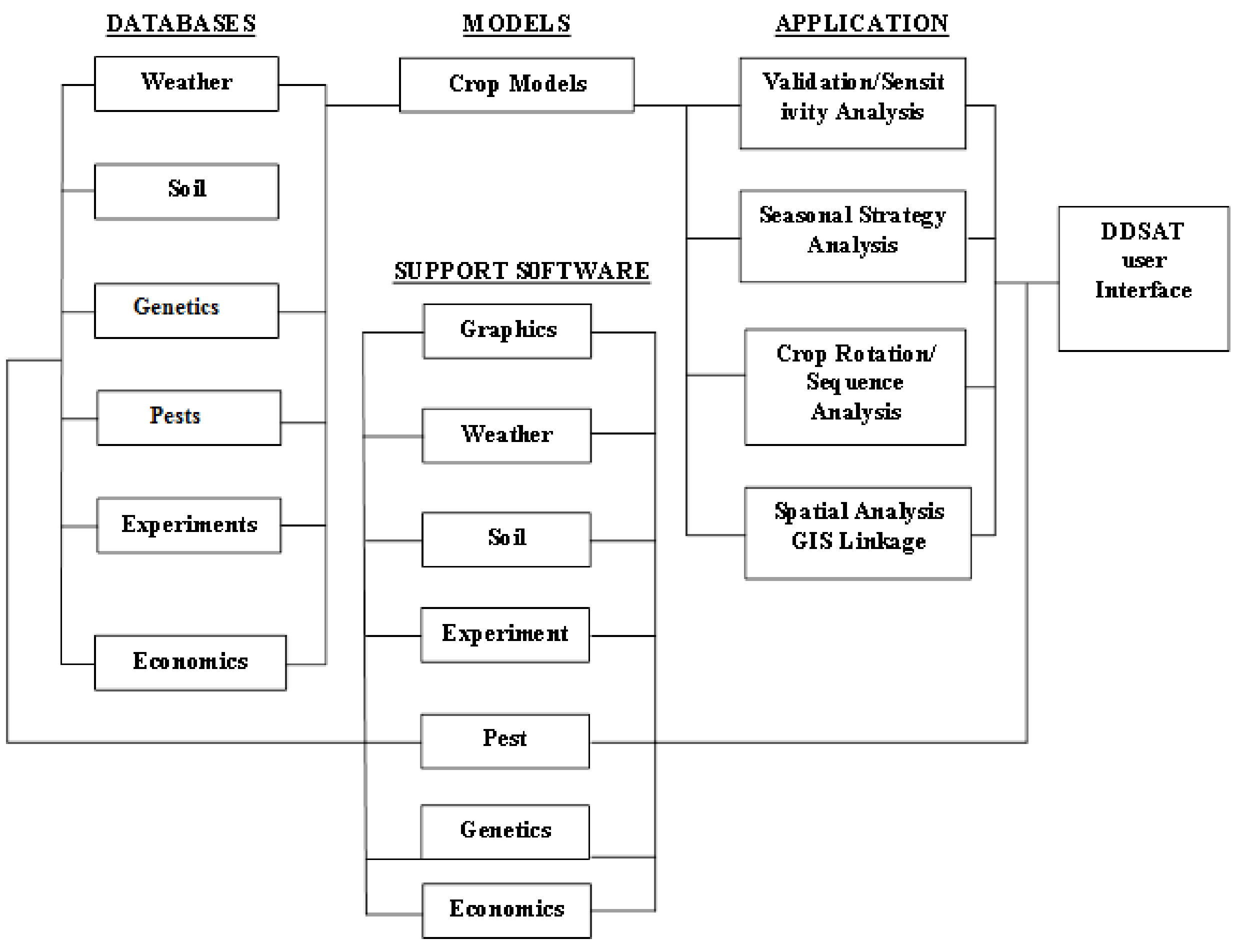


Figure 3. 2 Different components and software applications of DSSAT (Source: Jones et al., 2003)

CHAPTER 4: FARMERS' PERCEPTIONS ON CLIMATE VARIABILITY AND ADAPTATION STRATEGIES TO CLIMATE CHANGE IN CINZANA, MALI

4.1. Introduction

Climate change causes extreme weather and unpredictable events which impact and increasingly affect crop growth, availability of soil water, soil erosion, droughts and dry spells, floods, sea level rise with prevalent of pest infestations and diseases (Adejuwon, 2004; Zoellick and Robert, 2009). Many studies have shown that climate change will highly affect the African continent and will be one of the most challenging issues for future economic development, particularly in the sub-Saharan Africa (Roudier *et al.,* 2011). Because most of the population rely on natural resources, they are often practical affected by climate variability and change, especially the poorest (Morton, 2007). Particularly, smallholder farmers in sub- Saharan Africa are strongly impacted (Sivakumar *et al.,* 2005). Local societies already have in-depth knowledge of local climate change and variability as parts of their local ecological knowledge, obtained and transferred through generations (Berke *et al.,* 2000). Several scholars on climate change perception deals with precipitation and temperature in terms of the annual amount, the length and annual distribution of rainfall (Deressa *et al.,* 2009; Fisher *et al.,* 2010). Meteorological data are used to confirm local farmers' assessment of climate change. However, some authors emphasized the need to consider climate in a wider context such as in health or polices (Mubaya *et al.,* 2012; Shackleton and Shackleton, 2012).

According to Parrry *et al*. (2007), climate change and agriculture are interrelated processes, both of which take place on a global scale. It is predicted that global warming will have important effect on agriculture (McCarthy *et al.*, 2001; Funk *et al.*, 2008). These determine the biosphere's capacity to produce enough food for the human population and domesticated animals. Overall impact of climate change on agriculture will depend on changes in average temperatures, rainfall, and changes in pests and diseases; (Fisher *et al.,* 2002). Studies show that Africa's agriculture will be affected negatively by climate change (McCarthy *et al.,* 2001; Dinar *et al.,* 2008; Pearce *et al.,* 1996). About 25-42 % of species in Africa could be lost, affecting both non-food and food crops. Habitat change has already been observed in some areas leading to species shifts, changes in plant diversity including plant-based medicine and food (McClean *et al.,* 2005). Eleven per cent of arable land will be affected by climate change in the developing countries, which might lead to a decrease of cereal production in up to 65 countries and about 16 % of agricultural GDP (FAO, 2005).

Climate change will hardly harm the agricultural sector in West Africa if any adaptation actions are not taken (Rosenzweig and Parry, 1994; Adger *et al.*, 2003), but the negative impact of climate change can significantly be reduced if appropriate adaptation practices are adopted (Waha *et al.*, 2013). The type of adaptation practices and strategies to be undertaken is to some extent first determined by famers' perceptions of climate change (Roncoli *et al.*, 2001; Thomas *et al.*, 2007).

It is widely acknowledging in the Intergovernmental Panel on Climate Change (IPCC, 2007) that global climate is changing. In the same way, there is general consensus that the Sahel will get hotter as a result of global warming. The temperature in the Sahel will increase by 1.2 ˚C in 2030 as compared to current temperatures. (Butt *et al.,* 2006). The Sahel is expected to heat up more than the rest of the globe because in-land areas will become warmer than temperatures over the oceans. In the Sahel, temperatures are already close to the maximum for plant growth, especially at the starting of the season. Experiments with different levels of shading showed that temperature has a pronounced effect on millet production in the Sahel (Vandenbeldt and Williams, 1992).

There is therefore, the need to know farmers perceive climate, changes in climate and the environment (Kemausuor *et al.*, 2011). In fact, perception of farmers of climate variability and how these perceptions determine the choice of coping or adaptation strategies (Vedwan, 2006), have been investigated by previous studies in West African Sahel (Akponikpe *et al.,* 2010; Kyekyeku, 2012; Zampaligré *et al*., 2013; Sanfo *et al.,* 2014; Traore *et al.,* 2014, Kima *et al.*, 2015). Climate change confirmed by most of the farmers up to 98 % of respondents was dependent on the geographical area and prevailing climate across five 5 countries of West Africa (Akponikpè *et al.,* 2010). In the Sahel, more proportion of farmers perceived the change to have started between 20-30 years ago or more while the majority of them perceived it to be less than 10 years ago in the Guinean areas. Farmers in Burkina Faso understood climate change variability primarily based on weather-crop interactions and on events that are associated with climatic fluctuations. Their perceptions were additionally shaped by the cultural frame. Farmers mentioned more erratic rainfall patterns, decreased rainfall amounts, increased temperatures, winds and radiation.

In Mali, small scale rural farmers are depended to agricultural sector which depend on rainfall for crop production. According to Butt *et al.* (2005), national agricultural production earnings in Mali will likely decrease from US$ 417 million in 1996 to US$ 256 million by 2030 because of climate change. In the Sahelian zone of West Africa, the rural societies whose livelihoods strongly rely on natural resources are already facing many challenges due to their harsh environment (desertification, recurrent droughts and sometimes floods) and poor socio-economic conditions (Mortimore and Adams, 2001).

This study aimed at assessing Cinzana farmers in the Sahel zone in Mali their perception on climate change variability and their adaptation practices to overcome or reduce the negative impact of climate change on their farming system as well as their livelihoods.

4.2 Material and Methods

4.2.1. Overview of the Study Area

This research was conducted in the Cinzana commune in the circle of Segou in the Segou Region of south-central Mali (Figure 4.1).

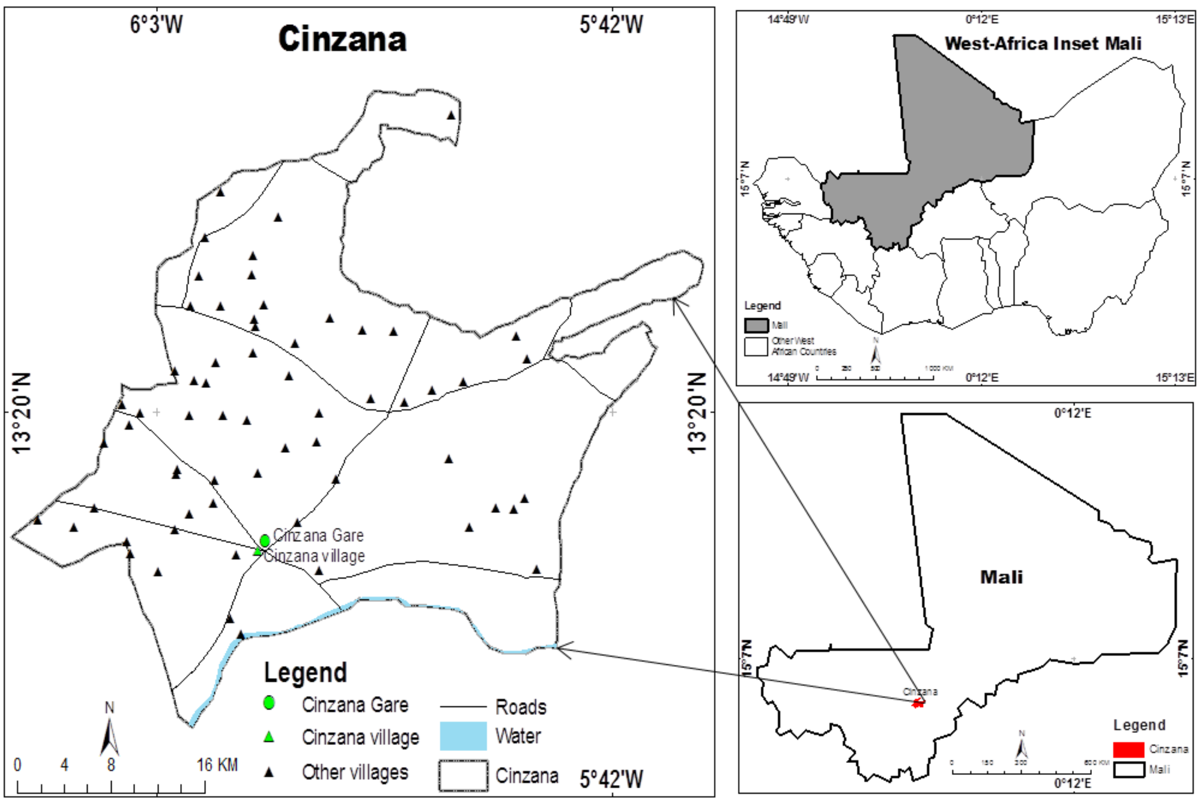


Figure 4. 1: The Location of the Study Area

Cinzana is located around latitude 13’15 N, longitude 5’58 W with an altitude of 289 m. The characteristic feature is the alternation of long dry season from November to May and raining season from June to October. The average annual rainfall of the last ten years is 650-750 mm. This amount which is unevenly distributed over the period is insufficient for the needs of crops which largely explains the successive years of crop failure. The average temperature ranged between 28-33 °C with 39-40 °C as the highest and lower threshold of 8 °C to 12 °C.

Cinzana rural town has a population of 37,572 composing of 18,727 (52%) males and 18,844 (48 %) females. The main economic activity of the commune is agriculture and the main crops are millet, sorghum and maize. The produce is primarily intended for home consumption because of poor rainfall, low soil fertility, and high cost of inputs which makes the production expensive. However, some farmers using improved technologies developed by the Institut D'Economie Rurale du Mali are able to generate surpluses that are traded on the weekly market at Cinzana. Farmers grow secondary crops like fonio, groundnuts, bambara groundnut, cowpea and sesame.

A series of on-farm surveys were conducted at Cinzana in 2013. One hundred and nineteen farmers' household including women and youth were randomly selected in the villages and were interviewed using structured questionnaire. The following formula was used to select the number of farmers:

$n = t^2 \times N/t^2 + (2e)^2 (N-1)$………………………………………….. Equation 4.1

t: Confidence level (value of the confidence level of 95% which is 1.96)

N= Size of the population (number of households in this case)

n: minimum sample size to obtain significant results for an event and obtain significant result for an event and a given level of risk

e= level of precision (state to 10% in this study)

Then the formula will be:

$n=\frac{1.96^2 N}{1.96^2+(2e)^2(N-1)}$ ………………………………………….. Equation 4.2

The structured questionnaire collected information on farming systems, perception on climate change and concerns for climate change. The questionnaire was designed in English and French but interviews were conducted in the local language, *Bambara.* The questionnaire was designed under the following 6 sections (see Appendix):

Section A describes the general information related to the farmers which included the socio-economic characteristics of the households and farming activities. Data collected were age groups, gender, educational level, secondary activity practices, household size, main crop, land holding, average duration of continuous crop farming, fallow use and fallow age.

Section B concerned farm production, which focused on food coverage, food self-sufficiency, crop yield and yield patterns for the last ten years.

Section C dealt with farmers' perceptions on climate change. The data collected were on climate change impact, the different measures taken by farmers against the climate change impact, access to meteorological data and meteorological data type, and the identification of traditional methods for predicting weather.

Section E was on vulnerability and climatic risk management. Data recorded were on mitigation and adaptation strategies, food security and main climate change adaptation strategies.

Interviews were conducted in November 2013. The questionnaire was pretested for its suitability before interviews were conducted. The pretesting include behaviour coding of interviewer/respondent interactions, interviewer debriefings, respondent debriefings and the analysis of item nonresponse rates and response distributions. Precipitation and temperature data were sourced from the Cinzana Meteorological station over the period from 1961 to 2014. The data gave an overview of the trends of precipitation and temperature and the vulnerability of the region to drought.

4.2.2. Data Analyses

Data from the questionnaire were coded and then analysed using the Statistical Package for Social Sciences (SPSS version 20) and MS Excel software. Descriptive statistical tool such as means, standard deviations, frequencies and percentages were used to summarize and categorize the information gathered. Cross tabulation was used to compare group's means. Correlation analysis was used to determine whether household income rather than education level significantly influenced adaptation strategies to climate variability and change. For the climatic variables analysis, the annual rainfall average and index of Nicholson (RI) which is a reduced central variable calculated on annual precipitation to highlight fluctuations in rainfall patterns were calculated. It is the ratio of the difference in inter-annual to average standard deviation of annual precipitation amounts. Nicholson indices play a very important role in determining precipitation fluctuations (wet, normal and dry period). Nicholson *et al.* (1988) cited by Paturel *et al*. (1997) have defined an index which is calculated for each year as

$$RI = \frac{Xi - \bar{X}}{\sigma} \qquad \text{Equation 4.3}$$

Where:

RI: Rainfall Index

Xi: Rainfall in year in millimeters

X: Average height of average rainfall over the period of study in millimeters σ = standard deviation of the rainfall over the study period.

The Nicholson index determines a reduced central variable (Lamb, 1982) as quoted by (Servat *et al.*, 1998). Inter-annual average of a series is the index zero (0) by the method of Nicholson.

4.3. Results and Discussion

4.3.1 Socio-Economic Characteristics of Respondents

About 92.7 % of famers interviewed in the survey were male headed households and aged between 36 and 55 years. Data showed that about 13.4% of household heads attended secondary school, 31.8 % attended primary school and 48.7% were illiterates. The average household size was more than 20 people by 55.6 %. Also, 52.1 % of the household heads were polygamous. The most experienced farmer in term of average duration of continuous farming was 50 years. Millet was the main cereal crop grown in the locality and is grown by 63 % of the farmers followed by sorghum 27 % and maize with 8 % (Figure 4.2).

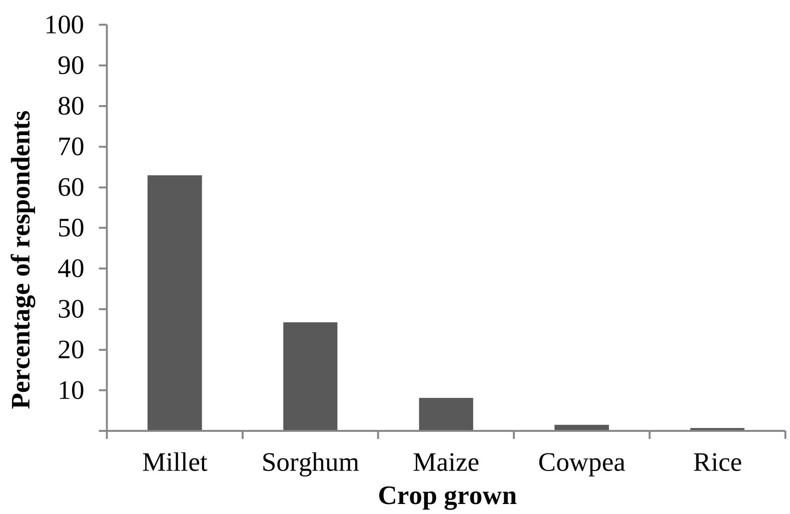


Figure 4. 2: Main Crops Cultivated by Farmers at Cinzana in 2013

Farmers found that millet contributed the most to satisfy their subsistence needs and income followed by sorghum and maize. The reasons for high cultivation of millet among farmers is attributed its high productivity, consumer preference and drought tolerance. About 46 % of farmers grew millet because of its high productivity, 16 % grew it because of its consumer preferred traits and 21 % cultivated millet because of its tolerance to drought (Figure 4.3).

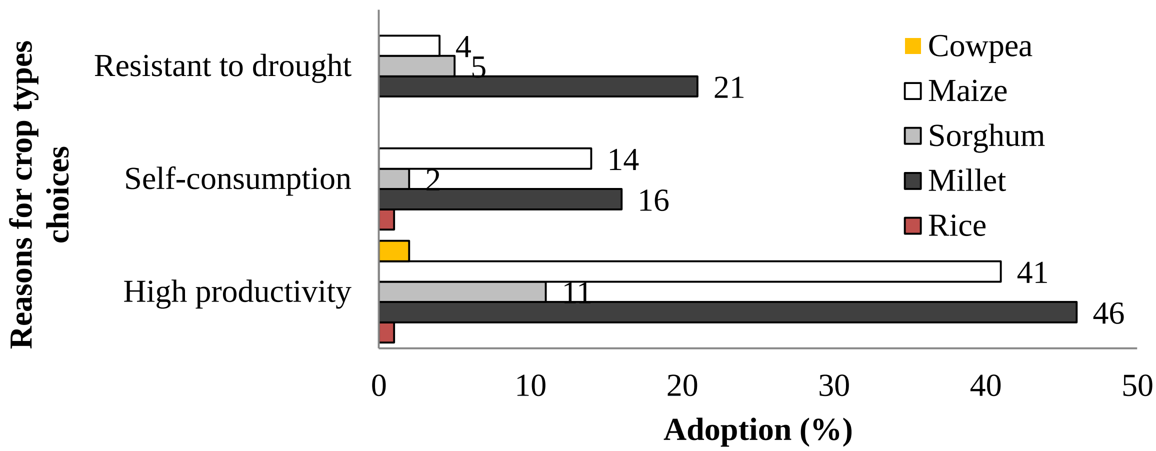


Figure 4. 3: Cinzana Farmer’s Reasons for Crop Choices

The population of Cinzana is dominated by relatively young people of less than 60 years old and male headed households. These male headed households are the active population in the locality. The main socioeconomic factors that impacted on adaptation decisions were level of education, gender and age of the household head, household size and years of farming experience. Effect of age on farmers’ adaptation to technology contradicts existing in literature (Teklewold *et al.*, 2006; Glwadys, 2009). In the view of Teklewold *et al.* (2006) and Glwadys (2009) adaption is mostly influenced by location or technology and specific findings of age are interesting empirical results. This is because the decision to adopt a technology is not easily accepted by older farmers compared to younger farmers.

The average size of a household in this locality was very large (20 persons) compared to many households in other locations in Mali. In Cinzana, female-headed households were non-existence as females are supported by men for subsistence according to their culture. However, women can practice some activities to improve their main source of income. Household size influenced the decision to adapt. Therefore, household size is a proxy to labour availability and may influence adoption of the new technology positively as its availability reduce the labour constraints (Teklewold *et al.,* 2006), However, there is a possibility that households with many family members may distract the labour force to off-farm activities in attempts to earn income to ease the consumption pressure imposed by the large family size (Tizle, 2007).

The gender of household head influenced the decision to adopt the change. Several scholars in Africa have shown that women have access to critical resource (cash, land and labour), which often undermines their ability to carry out intensive labour agriculture innovation (Quisumbing *et al*., 1995; De Groote and Coulibaly, 1998). According to Nhemachena and Hassan (2007), female-headed households are more likely to take up climate change adaptation methods. A number of studies found that, the possible reason for this observation is that in most local smallholder farming communities in the region, men are more often based in towns and much of the agriculture work is done by women (Nhemachena and Hassan, 2007; Quisumbing *et al*., 1995; De Groote and Coulibaly, 1998).

However, level of education and literacy rate provides information about development at regional and national levels and they reflect people’s chances of alternative sources of income and livelihood. The literacy rate among farmers in Cinzana is substantially very low, only 13.4 % of people have attained secondary education. The farmers who attained secondary education level rely firstly on subsistence farming as their main source of income. Education level is often an assumption to increase in the understanding of adoption a new technology (Adesina and Forson 1995; Daberkow and McBride, 2003). This is because education is expected to increase the ability to receive, and understand information relevant to making innovative decision (Wozniak, 1984).

With an average rainfall of 650 mm in Cinzana, millet is largely cultivated, particularly on marginal lands. These areas are further characterized by variable and a short rainy season, irregular rainfall and a high evaporative demand (high radiation and temperatures). Lastly, the soils are acidic with low mineral fertility (especially low in phosphorous) and organic matter content. For all of these reasons, millet is considered to be the farmers preferred crop in Cinzana because of the low rainfall and adverse soil factors. Experience of farming probably increase the uptake of all adaptation option because of farmers' experiences that make them have better knowledge and information on change in climatic conditions as well as crop and livestock management practices (Hassan and Nhemachena, 2008).

4.3.2. Farmers' Perceptions of Climate Change and Variability and its Impacts on Their Farming System

All the respondent in the region believe that the climate is changing and is no longer as it was some years back. Each farmer gave their perception on each of the following factors: length of rainy season, soil fertility, crop yield, vegetation cover, temperature and drought. Figure 4.4 indicates that 94.1 % of the respondents perceived a decrease in the length of the rainy season.

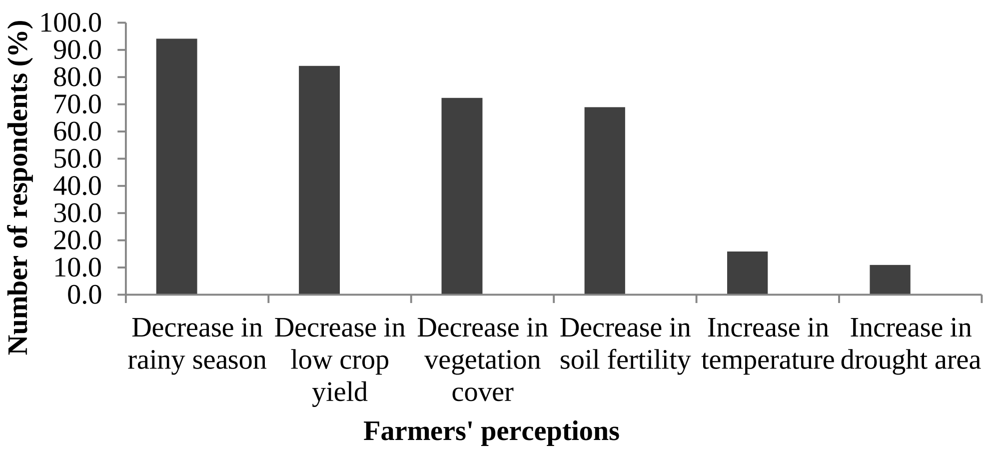


Figure 4. 4: Farmers' Perceptions of Climate Change and Variability in Cinzana Community in 2013

The respondents perceived a decrease in soil fertility as represented by 68.9 % (Fig. 4.4). Most of the soils in the locality were very poor in fertility. About 27.7 % of the farmers interviewed indicated that the loss of the vegetation cover was due to climate change. Surprisingly, only 15.9 % of the respondents' had perception of climate change indicated a decreased crop yield; 10.9 % of respondents observed temperature while 8.4 % found drought change over the years.

The farmers were using local knowledge to predict weather. More than 50 % of the farmers traditionally referred to tree flowering in the region for weather prediction while 38% use animal migration. Other less important factors are direction of wind (4.2 %) and change in temperature (1.6 %) (Figure 4.5).

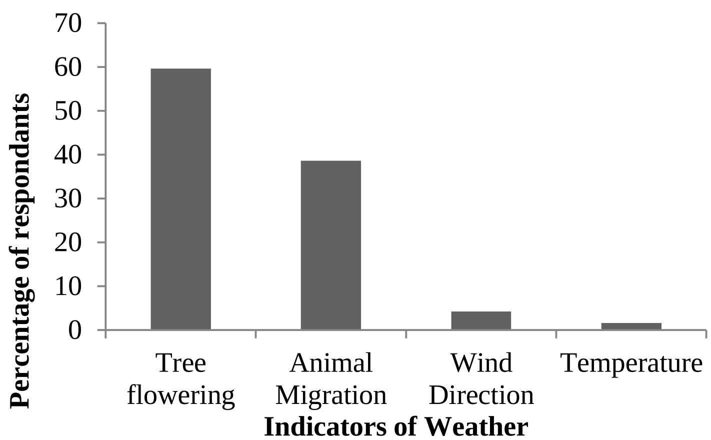


Figure 4. 5: Traditional Methods to Perceive Climate Change and Variability for Cinzana Commune Farmers

Furthermore, the respondents were asked about their perception on climate change and climate variability and their effect on the environment. Most of the farmers (87 %) indicated that agricultural areas have expanded followed by more vegetable cultivation and lowland cultivation with 69% (Fig. 4.6) They also found that forest areas (trees) have reduced by (65 %) and the savannah (the grazing area) has also decreased (61 %). Figure 4.4 indicates that 94.1 % of the respondents perceived a decrease in the length of the rainy season.

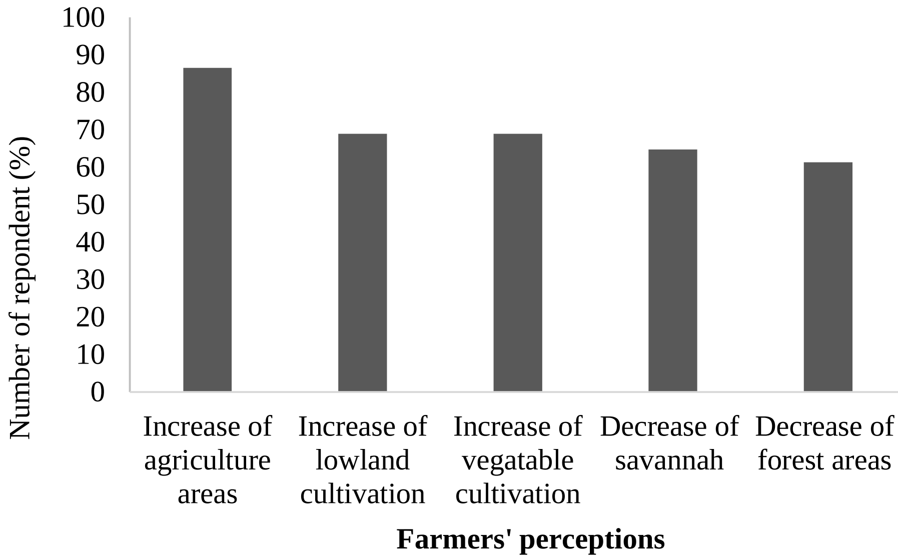


Figure 4. 6: Effects of climate change as perceived by farmers in Cinzana

Smallholder farmers in Cinzana are aware of climate variability and change, principally through their experiences by appreciating the length of the rainy season, soil fertility, crop yield, vegetation cover, temperature and drought. Some changes were observed on farmers' knowledge as factors used to predict weather. These included change in flowering period for some trees in the region, animal migration especially some birds, wind intensity and direction and high temperatures. This perception agrees with the general opinion that climate is changing (IPCC, 2007; McCarthy *et al.*, 2008; Orindi and Eriksen, 2005; Lobel *et al.*, 2013; Alexander, 2013). Furthermore, studies on farming perception in semi-arid environment of Africa (Nyanga *et al.*, 2011; Osbahr *et al.*, 2011) and farmer perception on climate variability and change in semi-arid Zimbabwe e (Moyo *et al.*, 2012) showed similar findings.

This study indicated that farmers at Cinzana believe that climate is changing, and it was perceived to affect agricultural productivity negatively. There is, however, divergence of perceptions amongst the farmers, as indicated by the results of what is causing the change in agricultural productivity. Famers reported a number of changes within their location; however, contradictions were apparent among them about the exact nature and the intensity of the changes. This may explain the different perceptions farmers have on effect climate variability and climate change have on agricultural production and productivity. Therefore, climate change and variability is often given as the main reason for crop failure and food shortage (Traore *et al.,* 2014; Mishra *et al.*, 2008; Sultan *et al.*, 2005).

4.3.3. Climatological Evidence Compared to Farmers' Perceptions

a) Rainfall and Temperature Variations

There were two periods regarding the rain season in the study area (Fig. 4.7). The dry period from 2000 to 2007 showing rainfall index supported by negative value index of this period, while the wet period from 2008 to 2012 showed a positive rainfall index value. The analysis showed the beginning of the dry period was supported by negative rainfall index for the 2013 year; which is in agreement with farmers' perceptions in this study. Overall there was a decrease of precipitation distribution during the 14 years of observations since 8 out of the 14 years indicated a negative index against 6/14 for the positive index. Rainfall is the most important variable that farmers perceived since it had a clear signal in the record of climate.

The analysis of temperature means during the same period showed a clear increase in temperature from 2000 to 2007 while from 2008 to 2012 it decreased (Figure. 4.8.). This was not in agreement with farmers in the study area. Few of the respondents perceived that temperature had changed, and could be explained by the fact that in the Sahelian agro ecological zone, farmers focus more on rainfall distribution than temperature.

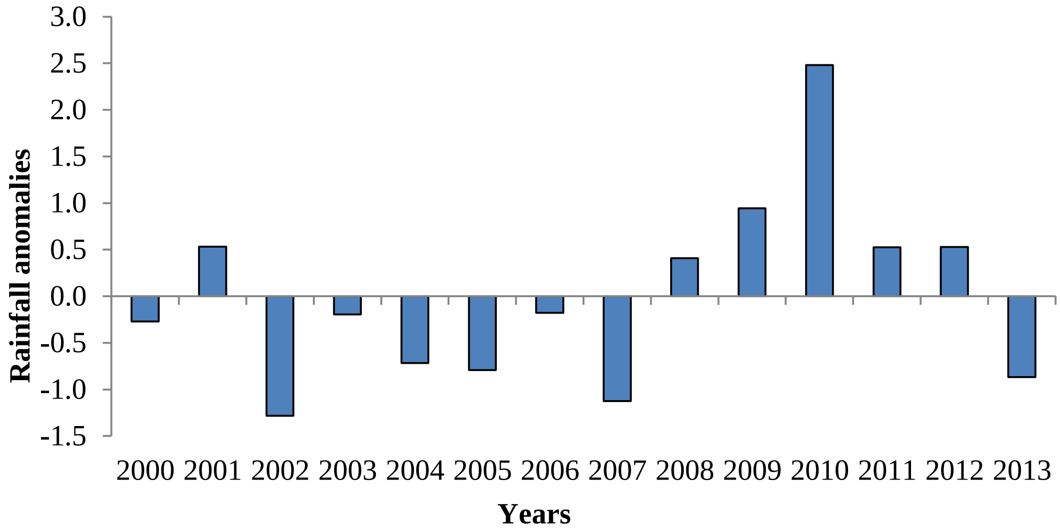


Figure 4. 5: Annual Rainfall Indexes (mm) from 2000 to 2013 in Cinzana (Data source: Cinzana Meteorological Station)

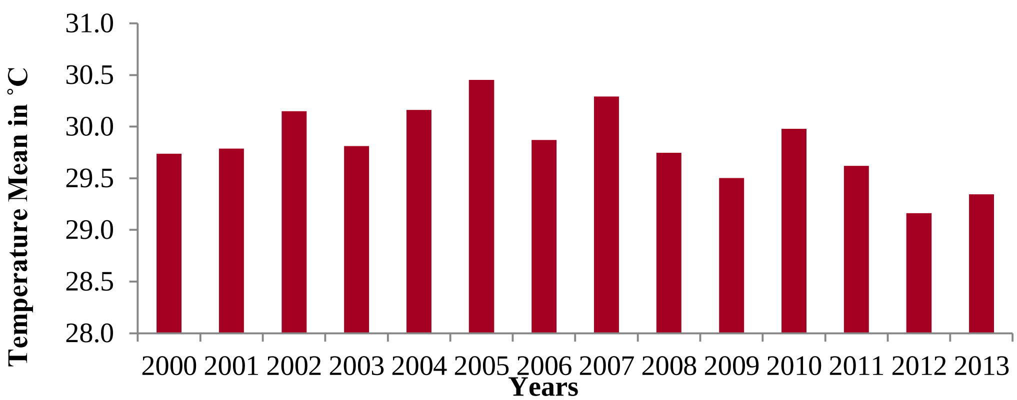


Figure 4. 6: Annual Temperature Means from 2000 to 2013 (Data source: Cinzana Meteorological Station).

The decrease of annual rainfall indicated by farmers was confirmed through an analyses of observed historical data in southern Mali (Mouhamed *et al.*, 2013; Traore *et al.*, 2014), showing an increase in the inter-annual rainfall variability. Furthermore, a study by Cooper *et al.* (2008) supports the same results for the Sub-Saharan Africa. In several countries, significant results between observed and farmers' perception of climate change and variability were found (Apata *et al.*, 2009; Deressa *et al.*, 2009). However, most farmers perceived a continuous decrease of annual rainfall which was not confirmed by the analysis of climate data. No clear change in total precipitation was observed over the last five decades in the Sudanian zone of Mali (Traore *et al.*, 2013). Changes in annual rainfall that farmers think they have been experiencing could be caused by the increase and decrease in the year to year variability of seasonal rainfall (Balme *et al.,* 2006). However, farmers may be reporting overall decline which could be attributed to temperature increase. For temperature, some farmers' perception of a substantial increase matches the empirical observations for the region very well (Hulme *et al.,* 2001). Farmers linked the temperature increase to a change in the number of drought days in the growing season, as these are perceived to be hot. Osbahr *et al.* (2011) showed that temperature increases led to increased evapotranspiration rates by linking to the faster depletion of soil water. Researchers found the high levels of depletion of soil water resulted from high rates of evapotranspiration normally leading to crop wilting, and causing crop failure, which the farmer may be attributing to a decline in rainfall.

4.3.4. Coping and Adaptation Mechanisms to Climate Change and Variability

To cope with the negative impacts of the perceived change in climate patterns on their farming systems, the majority of the farmers in the study areas have adopted some adaptation strategies and coping practices. Among these practices, the most commonly adopted strategies were the use of adapted crop varieties such as drought or pest tolerant crop varieties, early sowing and the use of organic mature as fertiliser. Other practices were the systematic use of chemical fertilizers, change in cropping system, more labour investment and rainwater harvesting. Table 4.1 indicates that about 75 % of the respondents interviewed used adapted crop varieties that are the most tolerant to drought for the zone while 73.1 % use early crop sowing for the different crop varieties to optimise the available moisture in the soil. Concerning organic manure use as an adaptation practice, 32.8 % of the respondents used this to reduce the impact of climate change and climate variability. Other strategies mentioned by respondents were the use of chemical fertilizer (28.6 %), cropping system (13.4 %) and rainwater harvesting (1.7 %).

Table 4. 1 Coping Strategies to Climate Change and Variability of Farmers in Cinzana Commune in 2013

Adopted practices	Farmer's response (%)
Adaptation practices	Yes
Variety adapted	75.6
Early sowing	73.1
Organic manure use	32.8
Mineral fertilizer use	28.6
Cropping system changes	13.4
Rainwater harvesting	1.7
Coping practices	Yes
Cropping system	65.5
Organic manure	63.5
Use of adapted crops	41.2
Rainwater harvesting	3.4
Livestock selling	0.8
Buying supplies	0.8

Results of adaptation strategies to climatic stressors undertaken by households are given in Figure 4.9. The major adaptation mechanisms include selling livestock especially small ruminants and poultry (42 %), utilization of improved crop seeds and seeking other activities outside agriculture (11.7 %), getting credit (10 %) and use of manure (8.4 %).

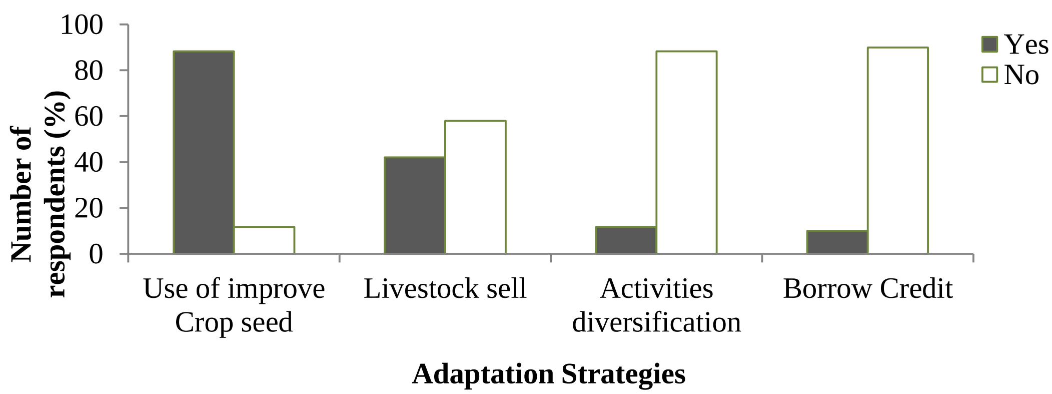


Figure 4. 7: Famers' Adaptation Strategies to Climate Change and Variability Stressor in Cinzana community in 2013

Descriptive statistics results have shown that farmers in the study area have adapted to the effect of climate change through a number of mechanisms. Households have multiple strategies related to agriculture and engaged in off-farm activities to complement their household incomes and food in case of adverse conditions in agriculture. The majority of respondents reported that they have used more than one type of adaptation and coping strategies. This decision implies that a single strategy is inadequate in adapting to the impact of climate change as a combination of several strategies is likely to be more effective than a single strategy. The major coping mechanisms to climate change undertaken by households were adapted crop seed varieties; which is different from the studies on coping mechanisms by Fana and Asnake (2012) in Ethiopia, Quay (2008), Kyekyeku (2012) in Ghana, and Bardege *et al.* (2013) in where? Who obtained various diversified coping strategies in response to climate change, which most of them related to the coping mechanism found in the study.

The findings reveal that households in Cinzana commune had several adaptation strategies in response to the effect of climate change and variability. The major strategies included use of adapted varieties, use of organic matter and selling of animals. This implies that climate variability and change is not a new phenomenon to the Cinzana commune. Those strategies are not strange but have a close relationship to those carried out elsewhere. However, a study done in 11 African countries by Nhemachena and Rashid (2008) found that diversified adaptation mechanisms to climate change such as diversifying production, using different improved varieties, changing planting dates, increased irrigation, use of insurance, water conservation, prayers, soil conservation were used., The adaptation strategies adopted in different regions or countries depend on their level of economic development, technology, financial capacity, institutional support and traditions. Therefore, each region tends to have most similar adaptation strategies adopted.

4.3.5 Correlation Estimation of Some Factors Influencing the Farmers' Adaptation Strategies to Climate Change Effects

To diagnose correlation, the contingency coefficient test was applied and omits independent variables that are strongly correlated and dependent to each other (Table 4.2). The study observed multi-correlation between age and farming experience, sex and farming experience, household size and number of farms, secondary activities and farming experience, sex and education, education and household size, sex and number of farms.

Table 4. 2 Correlation of factors studied on adaptation mechanisms in Cinzana commune

	Ag	Gen	Edu	Hldsize	Adpstra	Farsize	Farexp	Income
Age	1							
Gender	-0.019	1						
Education	-0.127	-0.177*	1					
HldSiz	0.169*	-0.122	.164*	1				
Adstra	0.057	0.099	-0.005	0.073	1			
Landsize	0.132	-0.184*	0.110	0.355**	0.013	1		
Farexp	0.208**	-0.228**	0.089	0.255**	-0.038	0.262**	1	
Income	0.004	-0.161	0.068	0.112	0.170	-0.057	-0.050	1

* Correlation is significant at 0.05 level
** Corelation is significant at 0.01 level
NB: Ag= age, Gen: gender, Edu= education, Hldize= household size, Adpstra= adaptation strategies, Farsize= farm size, Farexp: farming experience

The results of correlation (Table 4.2.) indicated a positive correlation (0.01 %) between age and farming experience. This means that farming experience significantly increase with increase in the number of years of the respondent in farming. Experienced farmers see the need to adapt to climate variability and change effects. Furthermore, these older farmers may be more interested in the following traditional methods familiar to them rather than adopting modern farming techniques. Acquah (2011) and Quayum *et al.* (2012) found similar results but negative significance. Their findings may be because young adults have more motivation to act on perceived changes in order to cope with it. The ability to adapt depends on individual's motivation to act (Bandura, 1997). Therefore, young adults are able and have energy to get jobs outside agriculture and can also diversify agricultural production which can help them get more income to adopt other adaptation. The influence of farmers' gender was negatively correlated to the educational level, the number of farms and highly correlated to the farming experience negatively. This influence of gender is because the males were more likely to adapt than their female counterparts since in many African traditions the females have less access to land and other socio-economic resources constraining the adaptive capacity of females to adapt to climate change and variability. It was reported by International Food Policy Research Institute (IFPRI, 2001) and Meinzen-Dich *et al. (*2010) on gender studies that unequal distribution of assets between males and females in rural households was in favour of males. The results from this study agrees with those results by Tenge and Hella (2004) and Nabikolo *et al.* (2012).

The study also showed a high correlation between the household size and the number of farms and farming experiences. Households with high number of people have more land and more experiences in farming. They are more likely to adapt than their counterparts with small land because those farmers may open up large gardens and plant more crops. People who own more land may rent out some of their land in order to generate more income for the household and be able to adapt more appropriately than those who have less land (Nabikolo *et al.* (2012). Advancing Capacity to Support Climate Change Adaptation (ACCCA, 2010) reported that large farm sizes positively influences adaptation strategies such as the use of growing trees and improved varieties of crops and livestock.

4.4 Conclusion

In Conclusion, the agricultural sector of Mali is largely led by small scale rural farmers and it is seriously affected by rainfall fluctuation. Millet was the mean cereal crop growing in Cinzana commune because of its high productivity, their own consumption and because millet is tolerant to drought. Cinzana farmers feel and perceive changes in the climate patterns. They do take measures to deal with the changing climate though they have limited knowledge of climate change as a scientific concept Farmers used various measures to deal with the changing climate and the most preferred measure is the use of improved crop varieties was the main adaptation. Gender, size of land and age of household head were the significant determinants of adaptation strategies.

CHAPTER 5: ASSESSMENT OF CHANGING TRENDS OF DAILY PRECIPITATION AND TEMPERATURE EXTREMES IN SOTUBAAND CINZANA IN MALI

5.1. Introduction

The anthropogony's problem of climate change has been identified by researchers and is a widely acknowledged issue in the political sphere during the last decades. The different emissions of greenhouse gases linked mainly with industrial production increase the global mean temperature via the greenhouse effect, affect the whole Earth system (Lavinia, 2011). These changes imply risks for human lives as well as natural ecosystems. In different parts of the world, climates are characterized by their variability which affects many sectors. Since the 1950s this variability has increased and particularly so during the latest decade, principally because of the increased concentration of anthropogenic greenhouse gases in the atmosphere as argued by some scientists (Trenberth *et al.,* 2007a; Hegerl *et al.,* 2007; Stott *et al.,* 2011; Solomon *et al.,* 2009, 2010). It is argued in this context that surface temperature has increased by 0.7 ºC over the last century with a significant warming in several regions and with the land areas warming faster than the oceans (Trenberth *et al.,* 2007a).

IPCC has provided since the early 1990's proof of accelerated global warming and climate change. The global average temperature in the last 100 to 150 years has increased by 0.76 ˚C (0.57 ˚C to 0.95 ˚C) (IPCC, 2007a). However, global rainfall trends are complex because of wide regional differences, gaps in spatial coverage and temporal shortfalls in the data. In addition, Traore (2014), showed evidence for increases in the frequency of both heavy rains and severe droughts in many regions of the world. It has been shown by all 21 General Circulation Models (GCMs) used by IPCC to project that in sub-Saharan Africa a temperature increase in the order of 3.3 ˚C and this will happen by the end of the 21st century. Regarding projected change in the amounts of rainfall in sub-Sharan Africa, the uncertainty is considerably greater and in several models do not agree on whether change in rainfall will be either negative or positive (Cooper *et al.,* 2008). Agricultural production in Africa is uncertainty associated with between and within season rainfall variability and remains a fundamental constraint to several investors who often overestimate the negative impacts of climate induced uncertainty. Climate change is likely to make matters worse with increases in rainfall variability being projected.

A combination of internal and external forces in West Africa makes the climate of the region one of the most erratic in the world (Zeng, 2003). Several scholars have characterized the rainy season in West Africa; most of them described the start and end of rainy season (Dodd and Jolliffe, 2001; Omotosho *et al.,* 2000; Diop, 1996) However, other studies were based on decadal, total or monthly annual rainfall analysis (Nicholson, 1980; Sivakumar and Salaam, 1994; Ati *et al.,* 2002). A good pattern of perception of the seasonal variability is critical because of the wide unstable rainy onset season and high temporal and spatial variability and by alternation between wet and dry seasons (Servat *et al.,* 1998). According to Traoré *et al*. (2007) present knowledge on the regional climate in Sudano-Sahelian area West Africa revealed that rainfall remains unpredictable. This unpredictability of rainfall is the most constraint for farmers who have to plan at the beginning of the cropping season (Piéri. 1989). The first rain is not always followed by the full start of the monsoon (Sultan and Janicot, 2003), afterward dry spell can occur, for instance during the early stages of the crop growth so that germinated plants may die off or seeds may not germinate properly. Otherwise, if sowing is delayed, the land may be too wet to till (Traore, 2014).

According to a publication of CEDEAO-Club Sahel/OCDE/CILSS on Climate and Climate Change (2008), in the West African Sahel, an increasing trend was observed in both maximum and minimum temperatures for all the three ecological zones (Sudanian, Sahelian and Sahel-Saharan) with temperature increasing at a faster rate. Therefore, climate change is perceived through extreme events which tend to modify the magnitude of the predicted climate, while this can be supported by the number of flood events having increased on average from less than 2 per year before 1990 to more than 8 or 12 on average per year during the 2000s (Sarr, 2011). In addition, the annual total rainfall evolution has been characterized by succession of wet years from 1950 to 1969, followed by a period with the persistence of dry years from 1970 to 1993. The persistence of dry years from 1970 to 1993 (Ali, 2011; L'Hote *et al.,* 2002) was found in the southward movement of isohyets by about 200 km (Diouf *et al.*, 2000). Ali (2011) showed that in the region after 1993, another type of variability characterised by an alternation between very dry and wet years to have begun. Furthermore, the same author indicates that while there is tendency of persisting drought in the Western Sahel, the east is experiencing gradual return to wetter conditions.

The occurrence of extremes is usually the result of different factors at different time scales. A large amount of the available scientific literature on climate extremes is based on the use of the so-called 'extreme indices', which can either be based on the probability of occurrence of given quantities or on threshold exceedance (Ly *et al.,* 2013). The same authors argued that several publications related to those extremes emerged in some specific countries in particular in the developing world where most of the time, data availability is always distributed by the meteorological service. In Africa particularly, very few studies document that, such changing climate is because of several difficulties in accessing daily meteorological data (Lamptey, 2009).

Therefore, the World Meteorological Organization (WOM), through the Climate Variability and Predictability (WMO/CLIVAR) Expert Team on Climate Change Detection, Monitoring Indices

(ETCCDMI), coordinated a series of workshops in different regions of the world to help scientists and national experts discuss and assure quality control of climate data. Some regional analyses were thus undertaken for the understanding of climate extremes and trends (Easterling *et al.,* 2003; Vincent *et al.*, 2005; Aguilar *et al.*, 2005). However, recent studies in Africa, when analysing daily climate in terms of trends and extreme indices revealed some significant increases and decreases in annual precipitation; increases in longest wet spells, increases in high daily precipitation amounts and average rainfall intensity (New *et al.,* 2006; Alexander *et al.,* 2006). Minimum temperature was found to have increased faster than maximum temperature, thus contributing to narrow the diurnal temperature range (Easterling, 1997; Caesar *et al.*, 2006). Thus, many indicators in the extreme indices can be analysed to further investigate the perception of changes in climate in widespread area in the West African Sahel where a few studies have documented the changes that occurred in those extremes (Ly *et al.,* 2013). This is why, it's important to set trends in climate variables as this will indicate the nature of climate-related adaptation and decision strategies employed by various stakeholders to improve their livelihoods in an agricultural-based economy (Makuvaro, 2014).

Annual rainfall in Mali is highly variable, ranging from less than 200 mm to 1300 mm. Climate change threatens to increase air temperatures and evapotranspiration, increase the risk of intense rainstorms, and increase the risk of heat waves associated with drought (Baptista *et al*., 2013). According to Diarra *et al.* (2007); Butt *et al.* (2005); and Jalloh *et al.* (2013), the literature on climate change in Mali makes a variety of predictions about the specific changes that will occur. In Mali, the impact of climate change on precipitation is varying on which global and regional combination climate models are used (Baptista *et al.,* 2013).

Climate change is expected to increase vulnerability in all agro-ecological zones of Mali through rising temperature and more erratic rainfall, which will have drastic consequences on food security and economic growths (Butt *et al.*, 2006; Dell *et al.*, 2012). Climate change projections from the Hadley Centre Coupled Climate Model (HADCM) and Canadian Global Couple Climate (CGCM), suggest that by the year 2030, Malian average temperature may increase by 1-2.75 °C and 2-4 °C before 2060 (Butt *et al.*, 2005; 2006; Konate, 2010). The impact of temperature on agriculture is of major significance since 1 °C rise is linked to a 2.7 % reduction in growth in agricultural outputs (Dell *et al.*, 2012). Rainfall characteristics are particularly affected by these changes in rainfall: the onset and ending date of the rainy season, the distribution and intensity of rainfall events (Traore *et al*, 2000; Konaté, 2010). The impact of these changes on rainfall characteristic is 20–60 % yield losses for agricultural productions by 2025 (Butt *et al.*, 2005). Here too, the biophysical basis is fairly clear-cut that rainfall characteristics affect water balance, more specifically water availability and evapotranspiration, plus plant physiology directly (Dell *et al.*, 2012). The objective of this study was to assess the changes in trends of daily temperature and precipitation extremes in Sotuba and Cinzana in Mali during the period 1961 to 2014.

5.2. Materials and Methods

5.2.1. Study Area

The study was conducted in Mali in two locations, Sotuba in Sudanian agro-ecological zone and Cinzana in Sahel agro-ecological zone. Annual maximum and minimum temperature means vary between 27- 44 ˚C and 11- 30 ˚C, respectively in Sotuba whilst in Cinzana they vary between 26-47 ˚C for maximum mean and 13-14 ˚C for minimum mean. The rainfall season is unimodal, with the onset of the rains occurring in the main agricultural areas from May to July and ending in September–October.

With an area of 245 km², Sotuba is located in the Sudan zone and has a tropical dry and wet climate with average highs for over 30 ˚C. Sotuba is very hot on average all years round with the warmest month being March, April and May. November to February is the coolest months. During October to April, rainfall is severe with little rain falling and virtually none between December and February. The rainy season occur with the peak in July, August and September.

Ségou is a town and an urban commune in south-central Mali that lies 235 kilometres northeast of Sotuba on the River Niger. The region of Ségou is characterised by a semi-arid climate and drained by two important waterways: Bani and Niger River. It has two seasons: a dry and rainy season. The dry season includes a cold period and a period of heat. The rainy season starts in June and lasts about four months until September and yearly rainfall average is about 600 mm. The harmattan is dominant in the dry season and it blows from north to south. The monsoon blowing from south-west is more frequent during the rainy season. The list of the meteorological station used in this study is given in Table 5.1.

Table 5. 1: Meteorological Sations Used in the Study

Station Name	Longitude	Latitude	Elevation (m)
Bamako	-7.95	12.53	289
Ségou	-6.15	13.40	320

5.2.2 Analysis of Extreme Events

a) Descriptive Indices of Extremes

To improve a constant perspective on observed change climate and weather extremes, ETCCDI (Expert Team on Climate Change Detection and Indices) has defined a core set of descriptive indices of extreme. The indices describe special characteristics of extremes including amplitude, frequency and persistence. The core set includes 27 extreme indices for precipitation and temperature. R-based software (RClimDex) which is user friendly was downloaded on line from http://www.r-project.org.

The most important key of the indices concept involves calculation of the number of day in year exceeding specific thresholds. Example of such "day-count" indices are the number of days with minimum temperatures below the long-term 10th percentile in the 1961-1990 base periods or number of days with rainfall amounts greater than 20 mm. Several ETCCDI indices are based on percentiles with thresholds set to assess moderate extremes that typically occur a few times every year rather than great impact, once comes in a decade weather events. The percentile thresholds for precipitation is calculated from the sample of all wet days in the base period and for temperature are calculated from five-day windows encountered on each calendar day to account for the mean annual cycle. The reason for choosing mostly percentile thresholds rather than fixed thresholds is that the number of days exceeding percentile thresholds is more evenly distributed in space and is meaningful in every region. Such indices allow straightforward monitoring of trends in the intensity or frequency of events.

b) Data, Homogeneity Testing and Quality Control

Daily minimum and maximum temperatures and daily precipitation for the two stations were provided by the Centre of Aghrymet of Niamey for Bamako and Ségou Meteorological stations for 1961-2014 periods and were chosen to investigate extreme precipitation and temperature and to optimise the number of significant trends and data coverage throughout the study area. Data quality and homogeneity testing as well as the detection and adjustment of inhomogeneous time series were carried out using RClimdex 3.2.0 package (Zhang and Yang, 2004) which is freely downloadable from the ETCCDMI website at: http://ccma.seos.uvic.ca/ETCCDMI/index.shtml.

As a first step, temperature and precipitation time series with more than 20 % missing values within the analysis period 1961–2014 were excluded. Outlier in the time series has been identified and temporal consistency was tested according to Aguilar *et al*. (2003). In the data quality control sub-routine, unrealistic data was found such as:

- days with negative or greater than 500 mm rainfall amount,
- days with minimum temperature equal to or greater than maximum temperature and
- minimum temperatures greater than maximum temperature values were detected and corrected.

Observational climate data can be influenced by different climatic effect, such as the relocation of weather station, land use changes, adjustments in instruments and observational problems. These effects result in homogeneity problems causing a shift in the mean of a time series, which could result in first order autoregressive errors. Also, in the quality control process, each time series was tested to ensure homogeneity in the whole dataset. The erroneous observations (i.e. the unrealistic data) were replaced with a code (-99.9) which is recognized as missing data by the RClimDex software package to avoid errors in the computation. After ensuring these measures, the stations data was assumed 100 % consistent to further execute the study hours (Peterson *et al.,* 2002; Aguilar *et al.*, 2003).

c) Climate Extreme Indices and Analytical Methods

The 27 ETCCDI indices agreed by the international community aim to monitor changes in "moderate" extremes and to enhance studies on climate extremes using indices that are statistically strong and cover a large range of climates and have a great signal-to-noise ratio (Min *et al.,* 2011). The indices are calculated from daily precipitation data (Peterson *et al.,* 2002; Karl and Easterling, 1999). From the core extreme indices, 4 extreme precipitation indices and 5 extreme temperature indices were selected for the present study (Table 5.2). All trends for indices chosen were calculated annually using the Software RClimDex 3.2.0.

Percentile indices were calculated using the standard reference period 1961 to 2014 to make results easily comparable with other studies using the same reference period. During the trend estimation of the percentiles – based indices, RClimDex 3.2.0 uses the boot- strapping approach to avoid possible bias within the reference period associated with the existing inhomogeneity (Zhang and Yong, 2004). During the calculation process, particular data requirement must be met in order to calculate indices value using RClimDex. An annual value is considered as incomplete if more than 15 days are missing in a year. A month will not be calculated when ≥ 3 days are missing, a year will only be calculated when all months are present. A percentile bases index will only be calculated if there is 70 % data present at least within the reference period. Additional ETCCDI-recommended standard criteria are applied as described in the RClimDex user manual online at: http:// etccdi.pacificclimate.org/RClimDex/RClimDexUserManual.doc.

In the study, statistical analyses were done over the last 53 years since 1961 including the current climatological base period of 1981–2010 as defined in the source code of the RClimDex. Plots and tables of trends for the period 1961–2014 for the selected indices (Table 5.2) were generated using the RClimDex, a developing script in R open source software (Core team, 2012). To determine the significance of the trends, Student t-test was performed and the resulting P value, which now serves as a criterion to define the class boundary, was used to analyse the null hypothesis that the trend is equal to 0. The trend for each index was considered significant when found ≤0.05.

Table 5. 2 Summary of rainfall and temperature indices used in the study

Element	Index	Descriptive name	Definition	Units
Rainfall	PRCPTOT	Annual total rainfall	Annual total PRCP in wet days (RR ≥ 1 mm)	Mm
Rainfall	RX5day	Maximum 5-day precipitation	Maximum 5-day precipitation	Mm
Rainfall	CWD	Consecutive wet days	Maximum number of consecutive wet days	Days
Rainfall	R99p	Extremely wet days	Annual total PRCP when RR >99th percentile	Mm
Tn	Tn10p	Cool night frequency	Percentage of days with TN <10th percentile of 1961–2014	%
Tn	Tn90p	Warm night frequency	Percentage of days with TN >90th percentile of 1961–2014	%
Tx	Tx10p	Cool day frequency	Percentage of days with TX <10th percentile of 1961–2014	%
Tx	Tx90p	Warm day frequency	Percentage of days with TX >90th percentile of 1961–2014	%
Tx	WSDI	Warm spells	Annual count of days with at least 6 consecutive days with TX >90th percentile of 1961–2014	Days

Tn and Tx are daily maximum and minimum temperatures, respectively

5.3. Results and Discussion

5.3.1. Temperature and Rainfall Indices

a) Temperature Indices

Temperature indices showed a general warming trend throughout the region during the period from 1960 to 2014 (Figure 5.1 and 5.2). The stations with negative trend (significant at the 0.05 level) and positive trends (significant at 0.05 levels) in some of temperature indices extremes are shown in Table 5.3. The regional annual series for temperature indices during 1960-2014 are shown in Figure 5.1 and 5.2. Over the 1960-2014 period, cold day (TX10p) and cold night (TN10p) showed decrease in warming with the trend of -0.028 and -0.029 respectively in Sotuba station but was not significant (Figure 5.1 a and Figure 5.1 c). However, warm day (TX90p), warm night (TN90p) showed positive increase in warming at the rate of 0.081 and 0.029 respectively (Figure 5.2 a, figure 5.2 c) and warm spells (WSDI) showed positive 0.049 (Figure 5.3 a) e). While in Ségou station, all the temperature indices showed a positive significant trends over the periods 1960-2014 cold day (TX10p) and cold night (TN10p) (Figure 5.1 b and d), warm day (TX90p), warm night (TN90p) and warm spells (WSDI) with 0.331, 0.631, 0.392, 0.292 and 0.78 respectively (Figure 5.2 b, figure 5.2 d and Figure 5.3 b).

Indeed, in Sotuba the result of the frequency of cold nights and cold days appears to be negative and slope meaning that the nights have become warmer. Warm nights, warm days and warm spells have also become more frequent. Figure 5.1 and 5.2 illustrate that, through the analyses of some temperature indices during the study period the frequent cold nights and of cold days' decrease while that of warm days and warm nights and also of warm spells increased. Whereas, in the Ségou region, the results showed a general positive trends in cold nights, cold days, warm nights and warm days and also warm spells (Figure 5.1 and 5.2). While the frequency of cold ones decreased the warm ones increased. These results were not the case for only this study or for Sahelian countries, but also for those in coastal countries because of temperature regime caused by the influence of ocean. Thus, the increase in temperature was much higher than the global warming trends.

Generally, positive trend in cold and warm extremes, found in this study are consistent with increasing trends in both warm days and warm night temperatures and decreasing trends in both cold days and cold night as well as in frequency of both extremes established for West Africa by New *et al.* (2006) who showed the number of cold nights and days have decreased and the number of warm nights and days have increased between 1961 and 2000. Several of these trends are statistically significant at 90 % level. Kruger and Sekele (2013) also found that in South Africa, warm extremes increased and cool extremes decreased for all the weather stations during 1962-2009 periods. Therefore, the warming trend observed means a higher demand on domestic energy consumption for cooling, higher evaporation rates from water bodies and irrigated crops, and a lower performance from livestock and agricultural crops. Furthermore, old persons are particularly vulnerable in such increases in temperature and may increase the level of mortality.

Table 5. 3 Trend per percentage and day with positive and negative slope of temperature indices extremes in Sotuba and Cinzana for 1960-2014 periods

	Sotuba (1960-2014)			Cinzana (1960-2014)		
Indices	Mean	Slope	P-value	Mean	Slope	P-value
Cold day (%)	10.48	-0.028	0.487	13.48	0.331	0**
Warm day (%)	9.15	0.081	0.084	6.95	0.392	0**
Cold night (%)	12.35	-0.029	0.685	17.71	0.631	0**
Warm night (%)	8.36	0.029	0.55	7.41	0.292	0**
Warm spell (day)	4.15	0.049	0.049*	3.67	0.278	0**

*Statistically significant trend at p-value = 0.05; **highly statistically significant trend at p-value = 0.05

In addition, a study done by Ly *et al* (2013) in the West Africa Sahel showed a general warming trend throughout the period from 1960 to 2010. Through some selected locations in the West Sahel, Ly *et al.* (2013) found steady warming during the study period. Indeed, while the cold night and cold days' frequency decreased that of warm nights, warm days and warm spells increased. This temperature increase can result in reduced fodder yield, an increase in evapotranspiration, a possibility of migration and conflict between livestock and crop farmers as well as in the economical, physical and psychological cost (Thornton *et al.*, 2009; Sirohi and Michaelowa, 2007). Further, this increase in temperature also has an impact on human health (McMichael *et al*., 2012). However, some authors (Ly *et al.*, 2013) found out that in the last two decades, the frequency of cool nights decreased about twofold going from 10.1 % to 2.9 %, 10.3 % to 7.4 %, 10.1 % to 4.2 %, and 10.2 % to 04.8 %, for Nouakchott, Bamako, Ouagadougou and Niamey respectively. The result in Ségou is consistent with this later finding in that station for the most general significant warming trends. This was not observed in Sotuba where only warm spells were significant probably because of the reduced ocean-land temperature gradient that is characteristic of the monsoon regions as shown by Trenberth *et al.* (2007b) and Giannini *et al.* (2008).

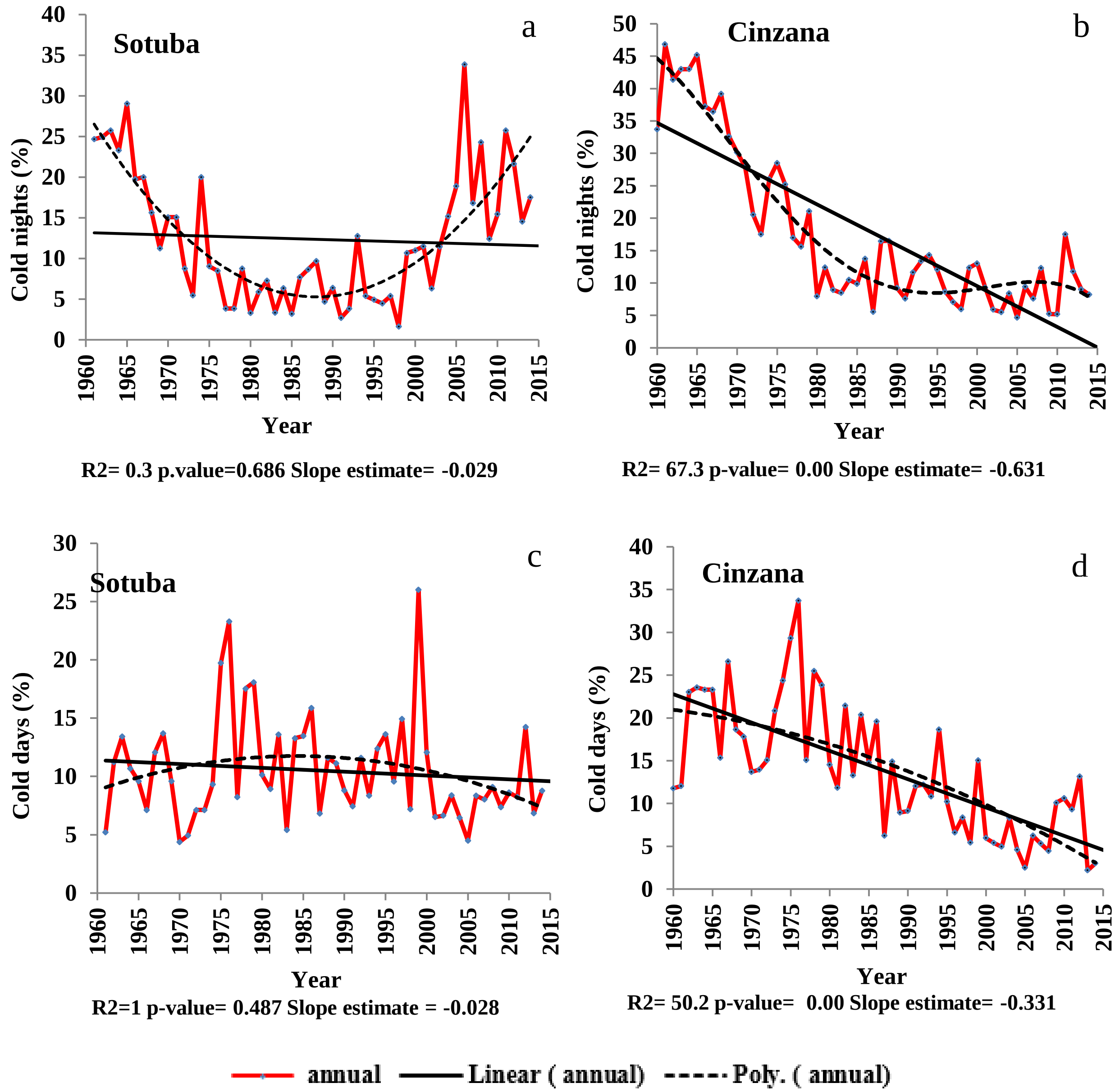


Figure 5. 1 Evolution of the percentage of cold nights (Tn10p) and that of cold days (Tx10p) in Sotuba (a and c) and Cinzana (b and d) from 1960 to 2014 period

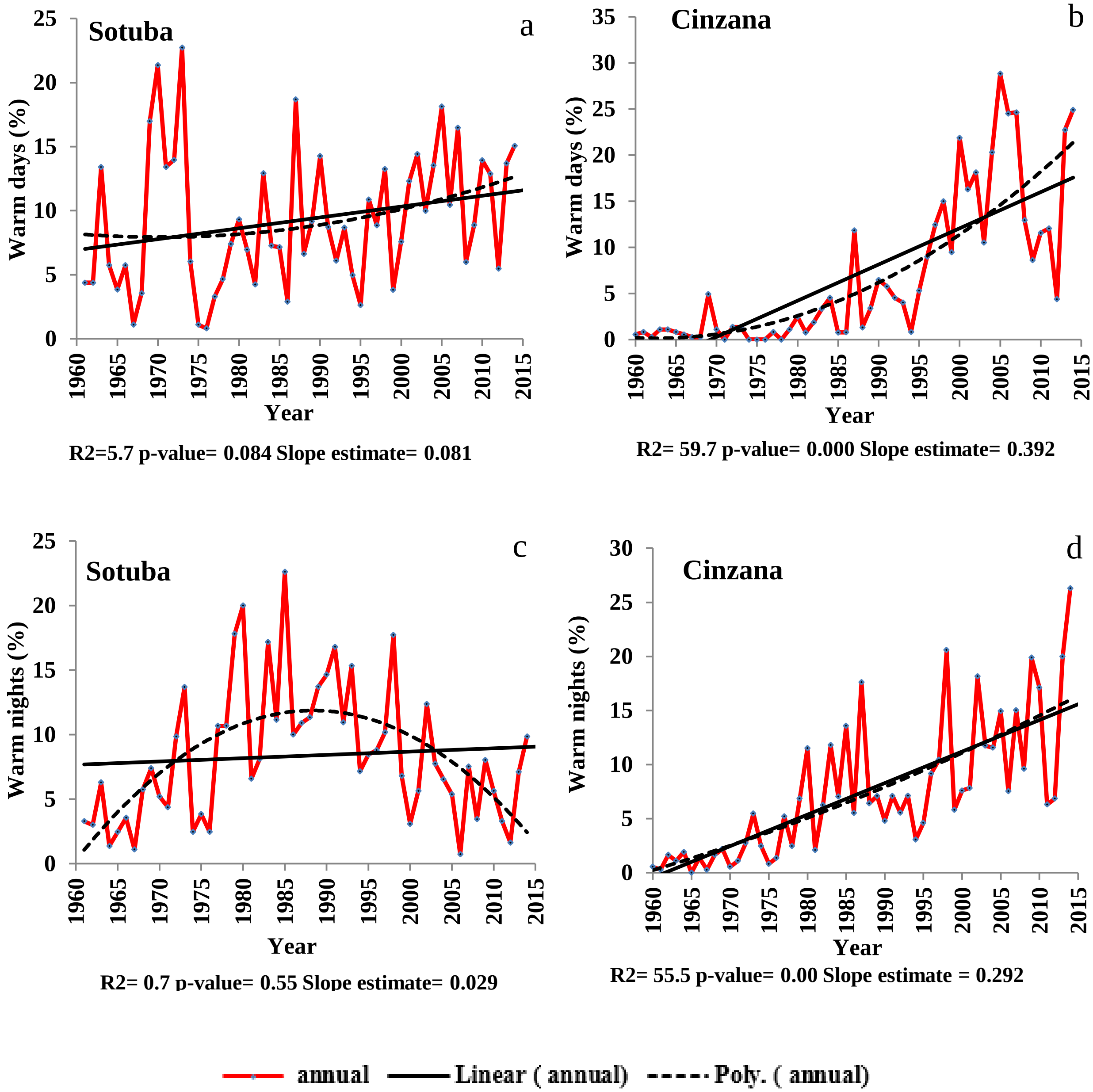


Figure 5. 2 Evolution of the percentage of warm nights (Tn90p) and that of warm days (Tx90p) and warm spells (wsid) in Sotuba (a and c) Ségou (b and d) from 1960 to 2014 period

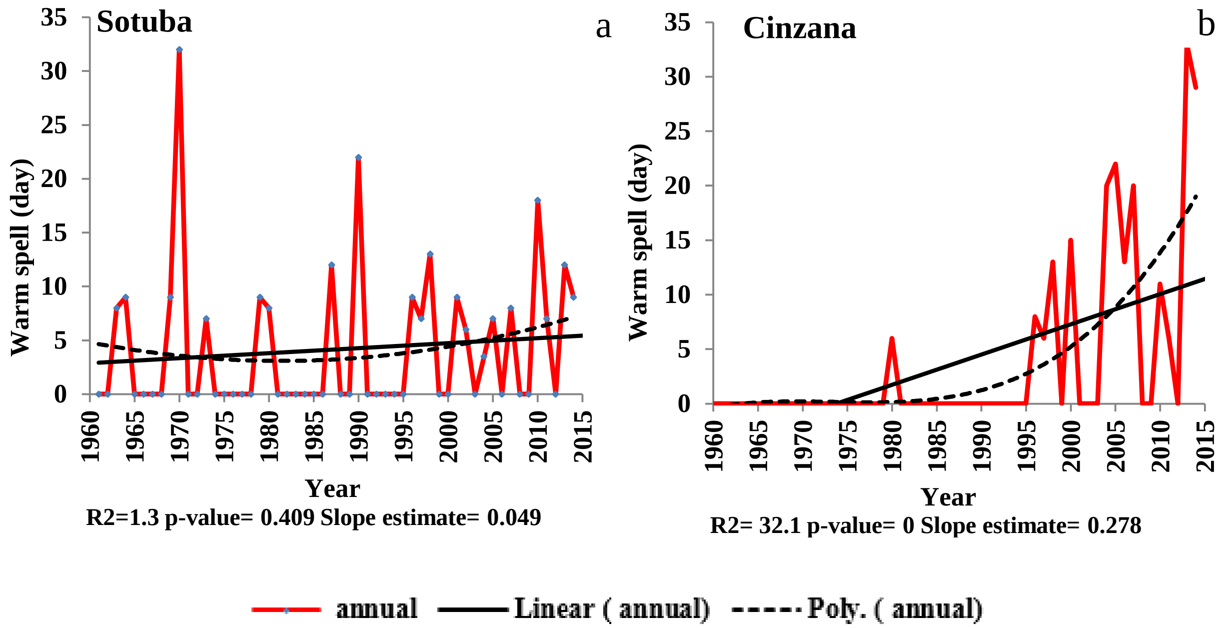


Figure 5.3: Evolution of the percentage of warm spells (wsid) in Sotuba (a) Cinzana (b) from 1960 to 2014 period

b) Rainfall Indices Extremes

Table 5.4 shows the regional trend in some extreme rainfall indices and the stations with negative (significant at the 0.05 level), no trend and positive trends (significant at the 0.05 level). The regional annual series for rainfall indices during 1960-2014 are shown in Figure 5.4. However, the results of precipitation extremes for Ségou showed positive significant decrease of 0.009 with negative slope trend, while consecutive wet days (CWD) (Figure 3b) and cumulated rainfall extremely wet days (RX99p) showed a positive slope and significant decrease with a rate of 0.00.9 and 0.029 respectively (Figure 5.4a). Whereas maximum 5 day's precipitation (RX5 Day) showed positive insignificant slope increase with 0.057 (Figure 5.3a) and the total annual precipitation (PRCPTOT) showed positive insignificant decrease with 0.541 with negative slope trend (Figure 4c). While in Sotuba, all the precipitation extremes showed negative slope trend. The consecutive wet day (CWD) (Figure 5.3c) and RX5p (Figure 5.3a) and total annual precipitation (Figure 5.4d) showed positive insignificant decrease at rates of 0.431, 0.459 and 0.97 respectively. Cumulated rainfall extremely wet day (R99p) showed positive insignificant increase with a rate of 0.852.

Rainfall trends related indices are not as uniform as the ones on temperatures (Figure 5.3 and 5.4). In Sotuba as well as in Ségou the results showed an overall reduction of rainfall over the 1961 to 2014 period. All indices in Sotuba revealed statistically insignificant, yet all the indices decreased in a moderate way (Table 5.4). However, in Ségou cumulated rainfall, extremely wet days and consecutive wet days showed statistically significant trends. Results showed that all rainfall indices, including both regions have declined over the last 53 years. That may be explained by natural variability and or a high response to increased greenhouse gases by anthropology or reduced aerosols (Haarsma *et al.,* 2005; Mohino *et al.,* 2011; Ackerley *et al.,* 2011; Biasutti, 2013). Rainfall represent meteorological element that best defines the climate of the tropics in general and of Mali in particular. Therefore, that decrease in rainfall clearly impacts well- being activities which rely on rainfed agriculture. The crop cycles follow the rhythm of rainfall. Precipitation is the main source of water during refuelling and layers. If any of the precipitation ever were to change, the consequence will be multiple for human life. Elsewhere, increased frequencies of extreme rainfall events such as long dry or wet spells mean weaker productive systems.

This decrease in annual total rainfall is confirmed in most part of Africa (Frappart *et al.,*2009; Ozer *et al.,* 2009; Hountondji *et al.,* 2011). Similar finding was observed of the overall reduction in rainfall in the studies over the Sahel (Biasutti, 2013; Mohamed, 2011; Ackerley *et al.,* 2011; Lebel and Ali, 2009; Nicholson *et al.,* 2000). It was also found in the study done by New *et al.* (2006) non- significant, but in total rainfall positive trends from heavy events for the West Africa and Southern Africa region. Therefore, for the increasing trend of cumulated rainfall of extremely wet days from the late 1980s, this is in accordance with the findings of Sarr (2011) and Ly *et al.* (2013).

However, extreme rainfall events became more frequent in the West African Sahel during the last decade, compared to the 1961 to 1990 period (Ly *et al.*, 2013). Furthermore, studies in other parts of Africa showed in some cases similar trends, but in other cases the trends were different. For instance, Kruger (2006) found some significant increase and decrease occurred in annual precipitation, some increases in the longest annual wet spells and some increases in high daily precipitation amounts in southern Africa over the 1910- 2014 period.

Table 5. 4 Trend per percentage, days with positive and negative slopes of rainfall indices extremes in Sotuba and Cinzana for 1961-2014 period

	Sotuba (1960-2014)			Cinzana (1960-2014)		
Indices	Mean	Slope	P-value	Mean	Slope	P-value
Maximums 5 days' rain (mm)	120.56	-0.209	0.459	100.16	1.68	0.057
Consecutive wet days (day)	5.11	-0.013	0.431	4.18	-0.029	0.009*
Extremely wet days (mm)	49.21	-0.105	0.852	22.76	2.156	0.029*
Annual total precipitation (mm)	929.64	-0.049	0.97	635.13	-0.856	0.541

*Trend statistically significant at p-value = 0.05

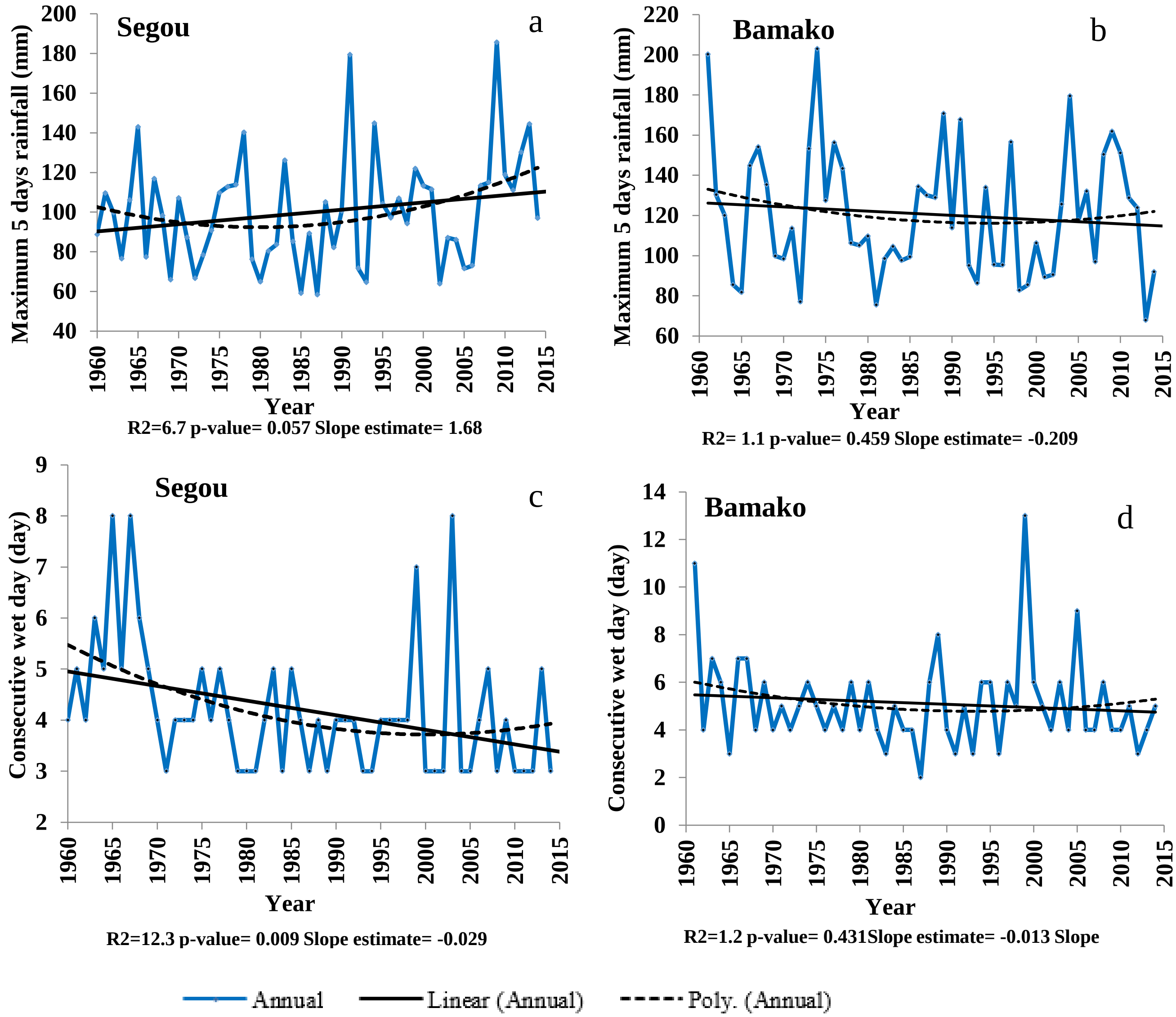


Figure 5. 3 Evolution of the maximum 5 day, precipitations (RX5 Day) and that of consecutive wet days (CWD) in Sotuba (a, b and d) Cinzana (a and c) from 1960 to 2014 period

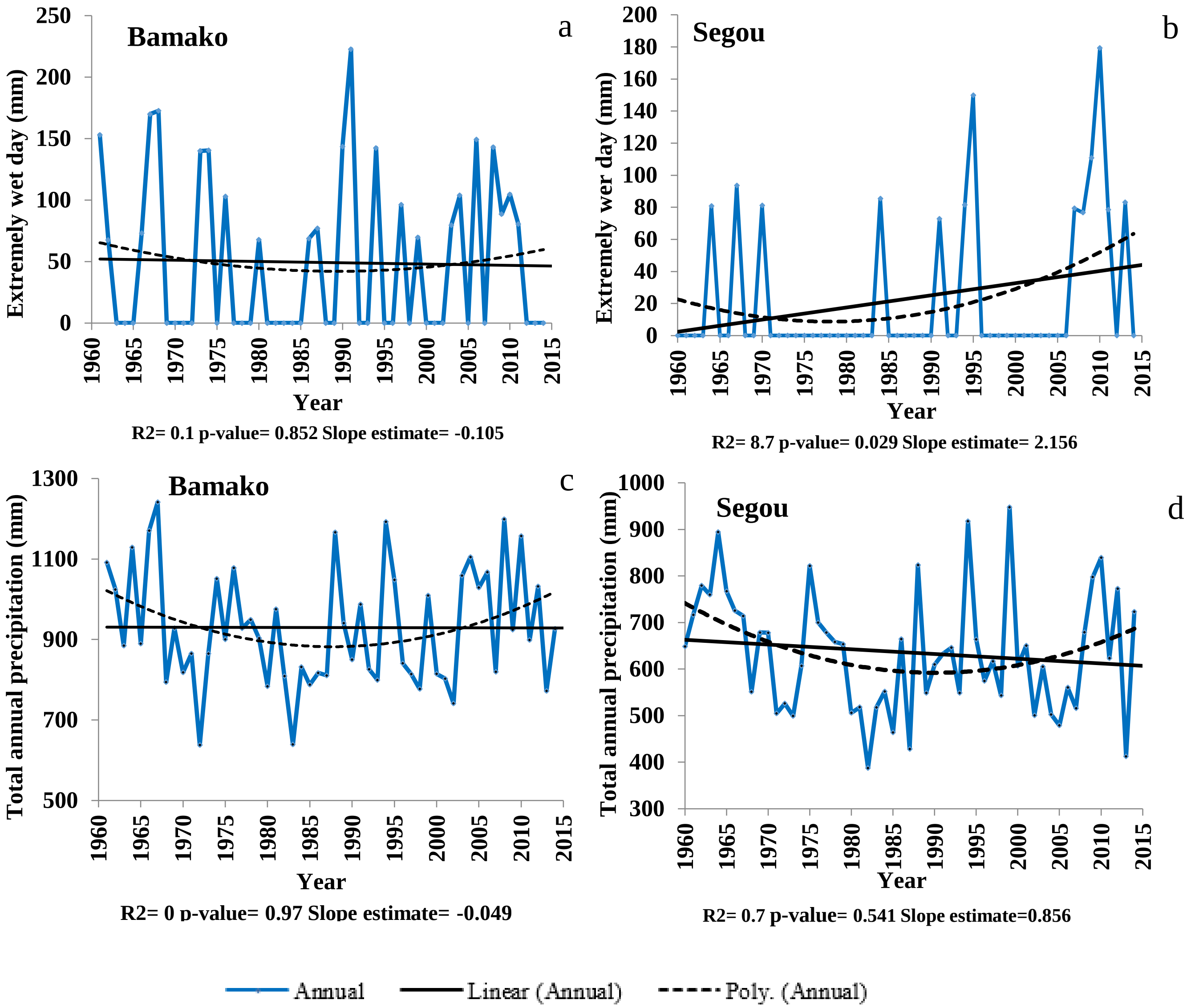


Figure 5. 4 Evolution of extremely wet days (R95p) and that of total annual precipitation (PRCPTOTE) in Sotuba (a, b and d) Cinzana (a and c) from 1960 to 2014 period

5.4 Conclusion

All temperature extremes in Sotuba and Cinzana showed warming trends in 1961- 2014 period. The warming trend was greater and significant in Cinzana than Sotuba. The finding of the study showed that there is a general decreasing trend for cold nights (TN10p) and cold days (TX10p) in Sotuba, while Segou showed high decreasing trend. A general warming trend in the temperature indices for warm nights (TN90p) and warm days (TX90p) since 1961 were observed. The significance of changes in precipitation extremes in Cinzana in 1960 and 2014 period was low, and only the trends in CWD and R99p were significant. In general, all precipitation extremes decreased, but the changes were not statistically significant.

CHAPTER 6: ASSESSING THE CHANGES IN YIELDS OF MILLET CROP UNDER DIFFERENT SCENARIOS OF CLIMATE CHANGE USING DSSAT MODEL

6.1 Introduction

In several region of the world, climate will probably adversely affect food production, especially in developing countries where a large fraction of the population already faces permanent hunger (Lobell and Burke, 2008). According to Dai *et al.* (2004) in sub-Saharan West Africa, the observed decrease in rainfall has been associated with an increase in temperature since the 1970s which has led to a decline in production (Barriose *et al.,* 2008; Traore *et al.,* 2013). IPCC (2013) showed that the projection of climate by the end of the century shows an increase of temperature by (1.1 ºC-4.8 ºC) and an increase of contrast between wet and dry season for the Sahelian region. Many studies assessed the impact of current and the future climate on crop production (Roudier *et al.,* 2011; Sultan *et al.,* 2013). Crop yields would decrease by 15 % probably because the effect of temperature decreasing the length of crop growth cycle and increasing water stress through higher evaporation losses even though the rainfall amount remains unchanged (Schlenker and Lobell, 2010). The impact of crop yield studies for Africa illustrates a wide dispersion of changes in yields ranging from -50 % to 90 % under various climate change scenarios (Roudier *et al.,* 2011), while the reported changes in crop yields are mostly negative (Challionor *et al.,* 2007). The projected impact is wider in the Sudano-Sahelian countries in West Africa, with an average yield loss of 18 % compared with an average yield loss of 13 % in the southern Guinean countries (Sultan *et al.,* 2013) and this difference is likely caused by the warmer and drier climates more in the northern countries.

Agriculture in Mali is very vulnerable to climate change. Rainfall remains uncertain for the future (Sultan and Janicot, 2003), while the increase in temperature is almost a certainty (Schwartz and Randall, 2003). This is a major challenge for agriculture which depends almost entirely on rainfall, as average temperatures would be close to highest values (1 to 2,75 ºC or more by 2030) (Oxfam, 2007) that could be harmful to the growth and development of crops. Crop production in Mali is essentially characterized by subsistence farming based on millet and sorghum in the Central and Northern region, and commercial agriculture dominated by growing cotton and rice in the southern regions and the centre. The yield of rice and cotton have seen a considerable increase (cotton 1 t/ha and rice 5 t/ha), while those of rainfed food crops (sorghum 0.8 t/ha and millet, 0.7 t/ha.) evolved slowly in the last 50 years, despite being the base of food for more than 80 % of the population (DNS, 1995).

In Mali, future crop yield will vary between -17 % and +6 % at the national level (Butt *et al.*, 2005). Negative impacts of climate change on crop productivity increase in severity as warming intensifies, emphasizes the importance of coping with global warming (Traore, 2014). The IPCC's fifth Assessment Report (AR5) presents new evidence of climate change (IPCC, 2013) and adapting cropping systems to the likely climate change is essential. Several adaptation options which help Malian farmers to cope with current climate variability could be considered (Traore, 2014). Farm production practices are in general: water management, fertilisation, crop land increases but also asset management/income as diversification of activities and migration (Chuku and Okoye, 2009). Changing the sowing date to the starting of the season is another common practice of farmers in the semi-arid regions (Muller *et al*., 2010). Studies for West Africa's crop simulation studies showed that sowing date and cultivar type adaptation can reduce the negative climate change impacts and increase crop yields (Tingem and Rivingto, 2009). The same authors showed a simulated 15 % and 40 % decrease in maize and sorghum yield respectively caused by climate change was converted to 32 % and 18 % increase respectively with the use of different variety with a longer crop growing period. Similarly, Butt *et al.* (2005) argued that by implementing adaptive responses such as the use of high-temperature-resistant crop varieties together with addressing soil fertility decline and economic gains could exceed losses caused by climate change in Mali.

Crop models simulation is the complex interaction between soils properties, management factors genetics, pest and weather that influence performance of crops. Simulation of crop modelling has developed over several years critical with advances in crop physiology, ecology and computing technology (Mukkar and Hassana, 2011). However, among the numerous crop growth models the most largely used are the Decision Support System for Agro-Technology Transfer (DSSAT) model which were designed to stimulate development, growth and yields of crop growing on a uniform area of land as well as the changes in carbon, nitrogen and soil water that take place under the cropping system over time (Jones *et al.,* 2003). An important task in models experiments is the testing of their performance in a large range of circumstances to identify their scope of limitations and validity (Mukktar and Hassana, 2011). The objective of this current study was to assess the performance of DSSAT model in simulating the yield of two millet varieties in the two selected agro-ecological zones of Mali under different scenarios of climate change.

6.2 Materials and Methods

6.2.1. Experimental Design and Crop Management

The computed data were obtained from two experiments conducted at Agricultural Research Station of Sotuba and Cinzana in 2013 and 2014. A combination of two pearl millet varieties and four fertilizer treatments were used. The fertilizers treatments used were: T1 Control (no application); T2 MANURE of 23:10:17 (5000 kg/ha); T3 NPK of 15: 15: 15 (50 kg/ha) and T4 combination of NPK + MANURE The experiments were conducted in a randomised complete block design (RCBD) with four replications in a plot size of 10 m x 4.2 m. The varieties evaluated at Sotuba station were Sanioni, an improved local variety and Cho, a local variety while at Cinzana station Sosat, an improved variety form IER /ICRISAT and IBV8001, and an improved variety from ICRISAT were used.

The land was ploughed, harrowed and ridged in the two locations. The experiments were established at Sotuba on 15th July, 2013 and 11th June, 2014 and at Cinzana on the 22th July, 2013 and 15th July, 2014. The plants were sown on 6 rows 5 m long, 0.80 m between rows and 0.50 m within rows (between hills). Plants were thinned to 2 plants per hill. Planting depth was approximately 3 - 5 cm and seeds covered with soil to enhance good germination and good seedling establishment.

Table 6. 1 Experiment layout for randomised complete bock design with four replicates

Replication I	**V_1T_3**	**V_1T_2**	**V_1T_1**	**V_2T_4**	**V_1T_4**	**V_2T_3**	**V_2T_1**	**V_2T_2**
Replication II	**V_2T_3**	**V_1T_1**	**V_1T_3**	**V_2T_1**	**V_1T_2**	**V_2T_4**	**V_1T_4**	**V_1T_2**
Replication II	**V_2T_4**	**V_2T_1**	**V_1T_2**	**V_1T_1**	**V_1T_3**	**V_2T_3**	**V_1T_3**	**V_2T_3**
Replication IV	**V_1T_4**	**V_1T_1**	**V_2T_4**	**V_2T_3**	**V_1T_2**	**V_2T_3**	**V_1T_3**	**V_2T_1**

Note: $V_{1=}$ (SANIONI an improved local variety in Sotuba site, and SOSAT an improved variety from IER in Cinzana site) $V_{2=}$ (CHO a local variety in Sotuba and IBV8001 an improved variety from ICRISAT) $T_{1=}$ Control, $T_{2=}$ MANURE, $T_{3=}$ NPK, $T_{4=}$ NPK +MANURE

6.2.2 Data Collected

Data were collected on all plants from the four central rows per plot in both locations. Data on seedling vigour were collected two weeks after planting and scored on a scale of 1 to 5 (1 = excellent, 2 = good, 3 = average, 4 = poor, 5 = very poor). The plant stand was evaluated as the number of plants of millet in each plot after thinning. The recording of day of 50 % heading was carried on the day at which 50 % in experiment unit plants started to have panicle from boot. The flowering was recorded when50 % of in an experimented unit had flowered.

The plant height was measured from the base of plant to tip of head at maturity. The data was taken on three plants per experimental unit and average three plants height were taken per plot. The number of harvested panicles was obtained by counting the number of productive panicles from the experimental plot. Panicle weight is the total of dry weight of the harvested panicle from the experimental plot. The numbers of hills harvested were collected by considering: numbers of harvested hills per plot that were taken; grain weight is the total grain weight of grain obtained after threshing the harvest panicles. Threshing and winnowing was done manually using sack and plastic bowls. After threshing and weighing, the seeds from the experimental unit, the weight of the 1000 grain was obtained and recorded. Grain yield was calculated using the following formula:

- $\text{Grain yield} = \frac{\text{Grain weight per plot x 10000}}{\text{Area harvested}}$……………………….. equation 6.1
- Straw weight was recorded by weight of all plant harvested and dried from the harvest unit.

6.2.3 Crop Model

The decision support system for agro-technology transfer (DSSAT)/CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time**.** A detail description of the model has been provided by Ritchie and Alagarswamy, (1989) and Hoogenboom *et al*. (2003).

6.2.4 Selection of Pearl Millet Varieties

DSSAT model is variety-specific and is able to predict millet yield and millet response to different environmental conditions. In projecting crop growth and yield, the model takes into account crop management, genetics, effect of weather and soil water, C and N. The model uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse management and weather conditions. However, in order to get trustworthy results from the model simulations, it is important to have the appropriate genetic coefficient for the selected cultivars. The two pearl millet varieties SANIONI and CHO for Sotuba site and IBV8001 and SOSAT for Cinzana have been selected in the present study. A specific cultivar coefficient for the genotypes used in these experiments was not in the list of cultivars available within the model. The cultivar coefficients were adjusted, until main development and growth stages were made for parameters of the development and growth, the aim being sensitivity analyses of the model and improvement of the coefficients. The coefficients were decreased or increased if needed using a small step.

6.2.5 Soil and crop management input.

Soils in these zones are mainly sandy and loamy of low fertility and seasonally waterlogged or flooded clays. They are classified as Lixisol in the FAO classification. Soil-related modules were parameterized mainly with measured data from experiments carried out under optimal growth conditions, and from related literature. Disturbed and undisturbed soil samples which were taken in soil profiles (0–10, 10–20, 20–40, 40–120 cm) prior to sowing, were analysed for organic carbon

(OC%), pH in water, and particle size distribution as described in Hoogenboom et al. (1999). Input data related to soil characteristics include soil texture, number of layers in soil profile, soil layer depth, pH of soil for each depth, clay, silt and sand contents, organic matter, cation exchange capacity, etc. The soil profile data used in the parameterization of the model is presented in Table 6.2 and Table 6.3.

Table 6. 2 Chemical properties at Cinzana site for model evaluation experiment

Depth (cm)	pH (w)	pH (KC)	Sand %	Silt %	Clay %	OM % C	N %	CEC meq/100mg
0-10	5.51	4.54	81.67	11.00	7.17	1.89	0.15	2.62
10-20	5.44	4.37	76.67	9.67	13.00	1.76	0.14	3.43
20-40	5.45	4.35	70.17	9.00	20.83	1.46	0.15	3.00
40-120	5.45	4.35	70.17	9.00	20.83	1.46	0.15	3.00

Table 6. 3 Chemical properties at Sotuba site for model evaluation experiment

Depth (cm)	pH (w)	pH (KC)	Sand %	Silt %	Clay %	OM % C	N %	CEC meq/100mg
0-10	5.77	4.83	72.06	21.28	6.59	1.32	0.88	5.47
10-20	5.70	4.63	70.13	19.25	10.69	1.24	0.85	5.10
20-40	5.75	4.61	66.59	19.19	14.13	1.14	0.73	5.44
40-120	5.75	4.61	66.59	19.19	14.13	1.14	0.73	5.44

6.2.6 Experiment for model parameterization for crop yield simulation

In the present study, DSSAT v 4.6 (CERES-Millet) (Jones et al. 2003) was used to simulate crop yields as a function of current as well as future climatological conditions. Data from an experiment carried out between 2013 and 2014 at Sotuba and Cinzana Agronomic Research Station under rainfed conditions were used to parameterize the models. Daily weather data during the growing season, were obtained from observations at the experimental stations. These include minimum and maximum temperatures, rainfall and sunshine hours which in turn are used to estimate solar radiation. Phenological data including planting date, date of flowering, date for start of grain filling and date of physiological maturity were collected. These were noted when 50% of plant population per plot attained each of these stages. The calibration was done using trial and error method of iteratively adjusting the parameters to obtain as close as possible the simulated and observed values of phenology (i. e. anthesis and maturity dates) and grain and biomass yields.

6.2.7 Modelling of Effect of Climate change and variability on millet grain yield

For climate change impact study, historical weather data was derived from the Agronomic Research Station for both sites for the period of 30 years from 1983 to 2012 and another 30 years' period projected weather from 2040 to 2070. The historical data were used to simulate grain yield variability on different pearl millet varieties for different treatments and also used as Baseline for the projected scenarios. Five scenarios were used based on GCMs (Global Circulations Models), where CMCC-CMS, CESM1-BGD, CCSM4, ACCESS1-0 and MRI-CGCM3 were described as Cold-dry, Hot-dry, Cold-wet, Hot-wet and Middle respectively. Cold and hot were defined as changes in temperature while wet and dry as changes in rainfall. Future weather scenarios used in the simulation for grain yields experiments were:

- Temperature increase (1.4° C) and (no change) in rainfall,
- Temperature increase in (2.4° C) and 10 % decrease in rainfall,
- Temperature increase in (1° C) and 30 % increase in rainfall,
- Temperature increase in (2.4° C) and 30 % decrease in rainfall,
- Temperature increase in (1.6° C) and 15 % decrease in rainfall.

The five GCMs were chosen based on their use in previous studies in the region and their better representation of projected climate, in terms of temperature and rainfall patterns in West Africa.

The simulations were made using a fixed concentration of atmospheric [CO_2] of 499 ppm for the Baseline (the value reported for the year 2010 in the fourth assessment report of IPCC.

6.2.8 Statistical Analyses

a) Experimental treatment

The effect of the treatments and their interactions were analysed for the four following parameters: plants height, 1000 grain mass, grain yield and straw yield, with ANOVA performed with GENSAT V.9 Discovery Edition 4, Release 10.3DE (PC/Windows 7), Copyright 2011, VSN International Ltd. (Roth Amsted Experimental Station).

Using the General Treatment Structure (in Randomized Complete Blocks), ANOVA model included treatments, year and their interactions. Duncan Significant Difference (DSD) test was used for post-ANOVA multiple comparison ($P < 0.05$) between means. Duncan significant tests were chosen because it can be used on raw data or in conjunction with an ANOVA test (Random complete block).

b) Data for model evaluation

The calibrated model was evaluated by comparing observed values for parameters of grain yield with those from model simulations. Model performance was assessed through various statistical parameters viz., coefficient of correlation, standard deviation, root mean square error (RMSE), relative error, model efficiency, were used to evaluate overall model performance (Loague and Green, 1991; Lecina *et al.*, 2003; Dust *et al.*, 2000; Ali *et al*., 2004; Liu *et al.*, 2011)

i. Root Mean Square Error (RMSE)

The Root Mean Square Error also called the Root Mean Square Deviation (RMSD) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. The individual differences are also called residuals and, the root mean square serves to aggregate them into a single measure of predictive power

i. $RMSE = \sqrt{\frac{\sum_{i-1}^{n}(P_i - O_i)^2}{n}}$.. Equation 6.2

where n refers to the number of observations, P_i and O_i signifies the simulated and observed values, respectively, and M denotes the observed mean value, according to Loague and Green (1991).

ii. Model Efficiency

EF = $\frac{\sum(measured - measure\ mean)^2 - \sum(simulated - measured)^2}{\sum(measured - measured\ mean)^2}$ .... Equation 6.3

6.3. Results and discussion

6.3.1. Inter-Annual Rainfall Variability, Rainfall Distribution and its Relation with Crop Yields for Sotuba and Cinzana

The rainfall distribution during the cropping season of 2013 and 2014 at Sotuba is illustrated in Figure 6.1 A and B. Overall, 60 to 75 % of the total rain fell between June and September in Sotuba. In the same location in that year, 2013 was the wettest year with 713 mm, compared to 2014 year with 640 mm. The distribution of rainfall also varied from year to year and the analyses showed that in 2014 the rainfall was better distributed than in 2013. In 2013, it was observed that a 7 days' dry spell occurred in September, while in 2014 no day dry spell occurred even though the rainfall started in April with 0.4 mm of rainfall. In both years, the end of the rainy season did not show any dry spell period.

Figure 6.1 C and D illustrate the rainfall distribution at Cinzana during the cropping season in 2013 and 2014. Though, 60 to 85 % of the total rain occurred between July and September in Cinzana.

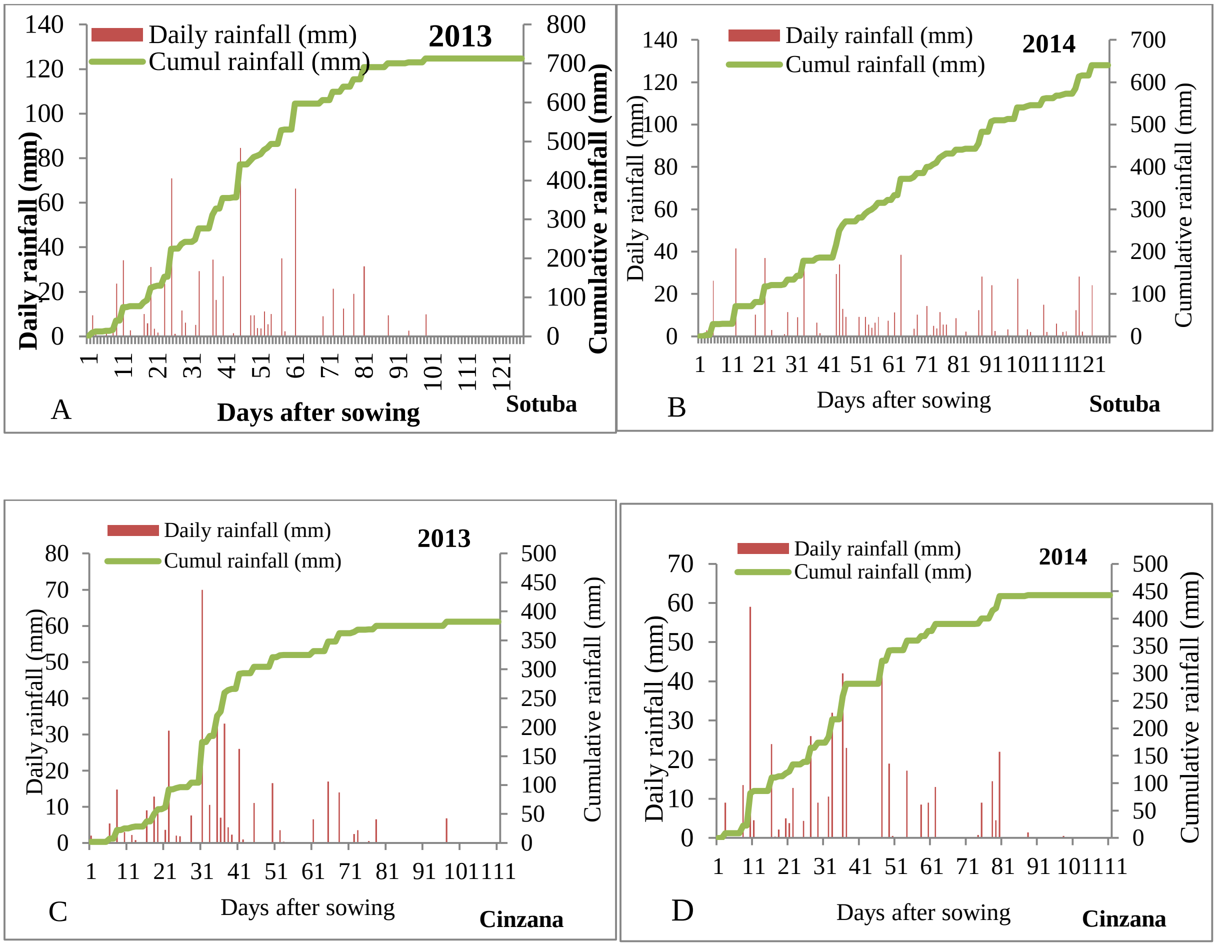


Figure 6. 1 Rainfall distribution in 2013 and 2014 in Sotuba (A and B) and in Cinzana (C and D)

Contrary to Sotuba, the year 2014 at Cinzana was wetter with 443 mm compared to the rainfall of 382 mm recorded in 2013. Two dry spells periods occurred in 2013 with 9 and 18 days' dry spell period in July and October respectively. In 2014 two dry spell periods was also observed with 9 and 11 days' dry spell periods in August and September. In both years, the rain started in April with rainfall of 0.4 and 6.6 mm for 2014 and 2013 respectively. The end of the rainy season was dry in 2013, with only 0.63 mm of rain in October against 0.91 mm in 2014. The rainfalls in both years at Sotuba were higher than that for Cinzana. This is expected because Sotuba is located in Sudanian zone while Cinzana is in the Sahelian zone. In 2013, dry spell periods were observed in both locations. Sotuba experienced only one dry spell period in year 2013 while it appeared twice in both years at Cinzana. The dry spell period at Sotuba that occurred in September corresponded to the flowering period of the crops. In 2013 at Cinzana the dry spell periods occurred in July corresponding to planting period of the crop while the one in October corresponded to the plant maturity period. The dry spell periods occurred in 2014 at Cinzana in August and September are the periods of the crop flowering and grain filling. Study done by Le Barbé *et al.* (2002), on rainfall variability in West Africa during the years 1950-90 showed similar results, where they defined that the ration between the number of rain events and the number of rainy day will depend on the location and period of year considered. In the Southern part of the West African Sahel the rainfall season starts earlier and end later than in the north (Traoré *et al.,* 2000; Traoré *et al.,* 2007).

The analysis of rainfall revealed sequences of dry spells which may affect crop yields. The highest in dry spell of 5 to 10 occurred in May and October (result not shown in the report). This showed the irregularity of rainfall in May which represents the land preparation in Sudanian-Sahelian zones of Mali, and which may delay the planting date and reduce the rainy season length for cropping period. Many farmers agreed that the rainy season which start early are mostly better for crop production than late rainy season (Sivakumar and Hatfield, 1990; Stewart, 1991). This is confirmed by the finding in 2014 at Sotuba by the researcher where the rainy season started early without any dry spell period in the cropping season resulting in higher yield. The date of started of rainy season was demonstrated to be the key variable to all other seasonal rainfall (Traoré *et al.*, 2014).

6.3.2. Analysis of Variance of Agronomic Parameters Studied

a) Plant Height

At Sotuba, the average plant height was 2.9 m and 3.6 m for 2013 and 2014 respectively (Figure 6.2) and CV of 10.9 %. The analyses showed high significant differences (<0.001) between the years for plant height (Table 6.4). It also showed a high significant difference (<0.001) between years and varieties interaction (Table 6.4). The plant height of CHO and Sanioni varieties varied according to year. At Cinzana, the average plant height observed was 2.3 m in 2013 and 3.6 m in 2014 and a CV of 11.7 % (Table 6.5). The analyses showed high significant differences (<0.001) between year 2013 and 2014 and did not show any statistical differences for any interactions.

Table 6. 4 Summary of analysis of variance on Yields and Yield components of two (2) varieties evaluated in Sotuba in the Sudanian agro-ecological zone

		F pr.			
Source of variance	df	Grain Yield kg ha^{-1}	Straw Yield kg ha^{-1}	1000 grain weight (g)	Plant height (m)
Years (Y)	1	**0.002**	**<.001**	**0.001**	**<.001**
Varieties (V)	1	0.683	**<.001**	**<.001**	0.094
Fertilizers (F)	3	**<.001**	**<.001**	0.223	0.256
Y x V	1	0.349	**0.003**	**<.001**	**<.001**
Y x F	3	**<.001**	0.261	0.397	0.449
V x F	3	0.631	0.816	0.245	0.944
Y x V x F	3	0.698	0.866	0.887	0.857
Residual	45				
Total	63				
CV%		18.1	20.0	8.4	10.9

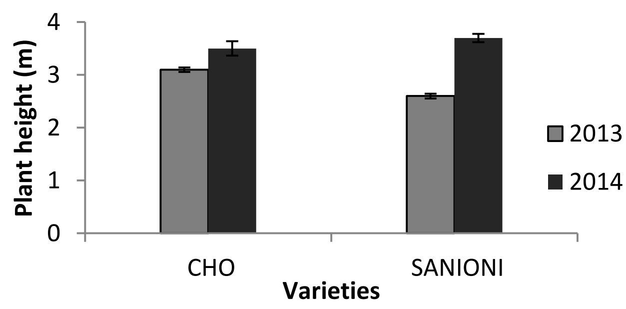


Figure 6. 2 Varieties for plant height yields in 2013 and 2014

b) 1000 Grain Weight

At Sotuba, the average 1000 grain weight was 9.6 g and 8.7 g for CHO and SANIONI, respectively. The analyses revealed significant differences between the two years (0.001) (Table 6.4). Highly significant differences were observed between varieties (<0.001) and the interaction between years and varieties (<0.001) was significant. In 2013, the variety CHO showed higher 1000 grain weight with 10.17 g compared to variety SANIONI (7.53 g) while in 2014 the variety SANIONI had higher 1000 grain weight (9.94 g) compared to variety CHO with (9.12 g). The 1000 grain weight gap between the year 2013 and 2014 for variety SANIONI was higher than that of the variety CHO for the same years (Figure 6.3). On the contrary, at Cinzana, the analysis did not show any statistically significant differences for the variable 1000 grain weight.

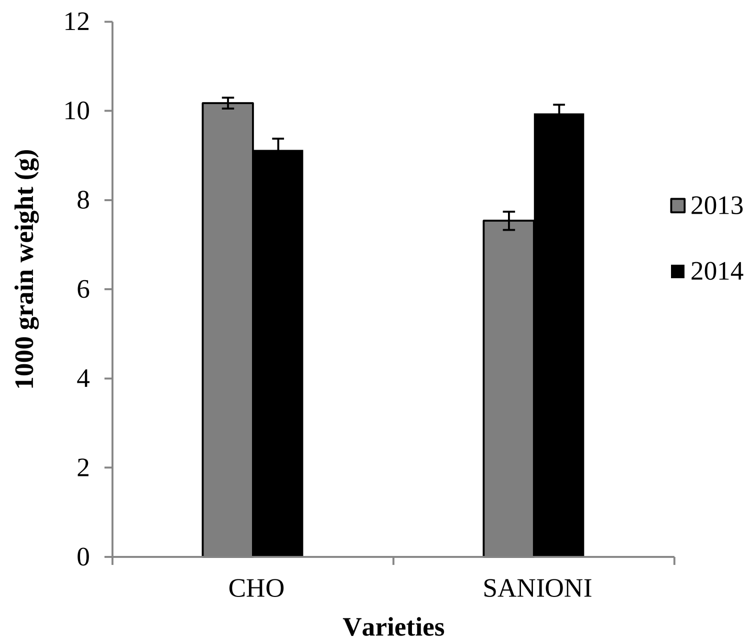


Figure 6. 3 Varieties 1000 grain weight in 2013 and 2014 in Sotuba

Table 6. 5 Summary of analysis of variance on Yields and Yield components of two (2) varieties evaluated in Cinzana a Sahelian agro-ecological zone

		F pr.			
Source of variation	Df	Grain Yield kg ha^{-1}	Straw Yield kg ha^{-1}	1000 grain weight (g)	Plant height (m)
Years (Y)	1	0.094	**0.04**	0.925	**<.001**
Varieties (V)	1	0.779	0.129	0.328	0.244
Fertilizers (F)	3	0.055	0.058	0.8	0.33
Y x V	1	**0.02**	0.452	0.791	0.236
Y x F	3	**0.002**	0.387	0.984	0.448
V x F	3	0.711	0.399	0.742	0.985
Y x V x F	3	0.2	0.331	0.691	0.821
Residual	45				
Total	63				
CV%		22.4	30.9	16.7	11.7

c) Straw Weight

At Sotuba, the average straw yield was 9714 kg ha^{-1} and 31487 kg ha^{-1} for year 2013 and 2014 respectively. The analyses revealed high significant differences between years (<0.001), between varieties (<0.001) and among fertilizer treatments (<0.001). Table 6.4 showed significant differences between years and varieties interaction (0.003) with a CV of 20 %. Figure 6.4 showed an interaction between years and varieties. The total straw produced in 2014 (34999 kg ha^{-1}) by the variety SANIONI was 3 times higher than produced in 2013 (1000 kg ha^{-1}) by the same variety. In 2014, the local variety CHO produced higher straw production with 27975 kg ha^{-1}. In 2014, the quantity of straw produced by SANIONI was higher than that produced by CHO while in 2013 both varieties had similar amounts of straw produced.

At Cinzana, the average straw quantity produced was 9270 kg ha^{-1} in 2013 and 7867 kg ha^{1} in 2014 and a CV of 30.9 % (Table 6.5). The analyses showed significant differences (0.04) between year 2013 and 2014 and did not show any statistical difference for the other factors and their interactions.

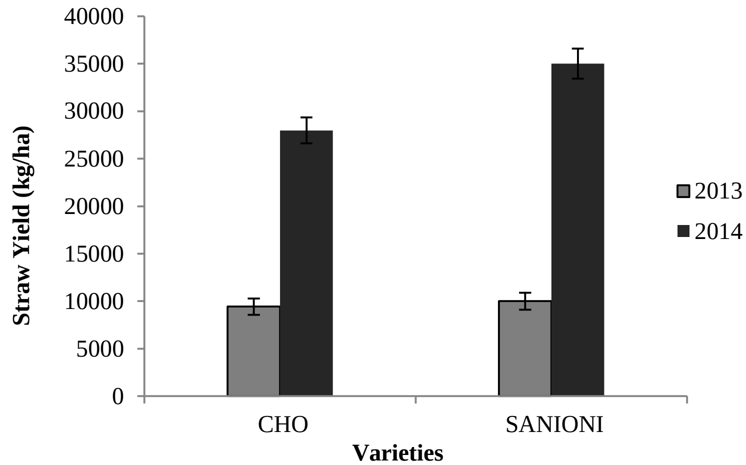


Figure 6. 4 Straw yields in 2013 and 2014 in Sotuba

d) Grain Yield kg

At Sotuba, the average grain yield was 1293 kg ha^{-1} and 1503 kg ha^{-1} for year 2013 and 2014 respectively. The analyses revealed significant differences between years (0.002). Table 6.4 showed high significant differences among fertilizer treatments (<0.001) and between years and fertilizer interaction (<0.001) with a CV of 18.1 %. In 2013, the analyses revealed high grain yield in the combined organic manure and NPK (NPK+MANURE) treatment with 1948 kg ha^{-1}, followed by NPK (1281 kg ha^{-1}), MANURE (1130 kg ha^{-1}) and Control (813 kg ha^{-1}). In 2014, the grain yield with fertilizer treatment (NPK+MANURE) was 1602 kg ha^{-1}, followed by NPK with grain yield (1502 kg ha^{-1}), MANURE was (1466 kg ha^{-1}) and control was (1440 kg ha^{-1}) (Figure 6.5). The grain yield gap for the Control treatment in 2013 (813 kg ha^{-}1) and in 2014 (1440 kg ha^{1}) was high compared to the NPK+MANURE, MANURE and NPK treatment grain yield gap for the same years.

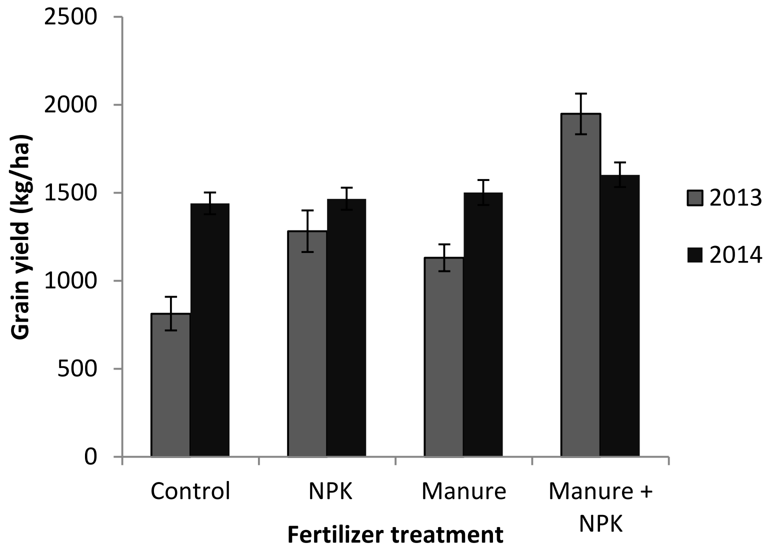


Figure 6. 5 Fertilizer and years for grain yields in 2013 and 2014 in Sotuba

At Cinzana, the average grain yield observed in 2013 and 2014 was 1390 and 1530 kg ha^{-1} respectively. The analyses did not show any significant differences between the varieties and among the fertilizer treatments. However, significant differences were found in the following interactions: years x varieties (0.02) and years x fertilizer treatments (0.002) with a CV of 22.4 % (Table 6.5). In 2013, variety SOSAT showed higher grain yield (1447 kg ha^{-1}) than IBV8001 (1333 kg ha^{-1} [1]) while in 2014, variety IBV8001 showed higher grain yield (1614 kg ha^{-1}) than SOSAT (1545 kg ha^{-1}). Figure 6.6a showed an interaction between years and varieties; thus, the grain yield gap of the variety IBV8001 in 2013 (1333 kg ha^{-1}) and in 2014 (1614 kg ha^{-1}) was higher compared to SOSAT in year 2013 (1447 kg ha^{-1}) and in 2014 (1545 kg ha^{-1}). In 2013, the analyses revealed higher grain yield with the treatments of NPK+MANURE, (1440 kgha^{-1}), NPK (1429 kg ha^{-1}), MANURE (1416 kg ha^{-1}) compared to Control (1276 kg ha^{-1}). In 2014, the Figure 6.6b showed the highest grain yield with NPK+MANURE (1915 kg ha^{-1}) followed by NPK (1561 kg ha^{-1}), MANURE (1523 kg ha^{-1} [1]) and Control (1121 kg ha^{-1}). The grain yield gap for the combined

NPK+MANURE treatment in 2103 (1440 kg ha^{-}1) and in 2014 (1915 kg ha^{1}) was high compared to the others for the fertilizer grain yield gap for both years.

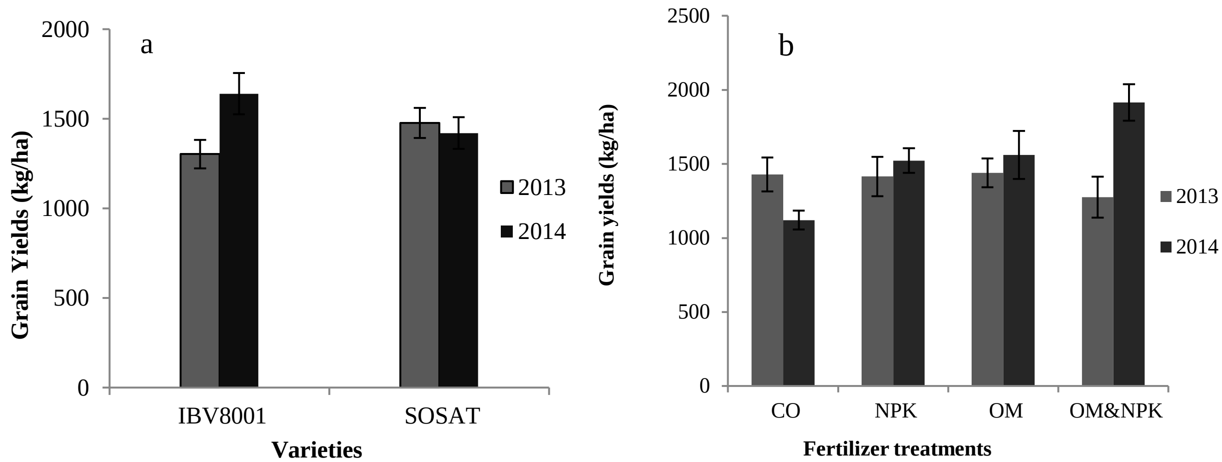


Figure 6. 6a and b. Year x varieties and year x amendments for grain yields in 2013 and 2014 in Cinzana

The rainfall at Sotuba in 2013 (713) and 2014 (640) were lower for the average rainfall of that location which was between 800 and 1100 mm. The same trend was observed at Cinzana with rainfall in 2013 (382 mm) and 2014 (443 mm) compared to the average rainfall between 650 and 800 mm. Rainfall is process by nature; therefore, lack of reliable rainfall covers the positive response of a crop to soil fertility management strategies for the crop productivity is increasing in West Africa Sahel (Bationo *et al.,* 1990; Rezaei *et al.;* 2014). At Sotuba the highest grain yield was obtained with NPK+MANURE treatment. The differences among the grain yields of the different fertilizer treatments compared to the Control were higher in 2013 showing the advantage of using fertilizer in the cropping system. At Cinzana, beside the low rainfall, the varieties showed differences according to the years and the fertilizer treatments. The differences among the grain yields of the different fertilizer treatments compared to the Control were higher in 2014 showing the advantage of using fertilizer in the cropping system. Furthermore, pearl millet is adapted to dry conditions and is sensitive to water stress particularly when this occurs during the flowering stage as was the case in the present study in 2013 and 2014 for the Cinzana location.

Millet is one of the most important foods in the Sahelian and the Sudano-Sahelian zones of Mali. The lower growth and yield parameters recorded in varieties could be attributed to uneven rainfall distribution, which cause water availability problems that affect soil aeration, amendment use efficiency and plant metabolism such as photosynthesis thus inducing good plant growth and development. Therefore, in this study, pearl millet responded positively to different fertiliser treatments imposed and manure application improved millet yield production significantly as compared to the no fertilizer (Control) application for both sites. There was a significant increase of grain yield production when manure was added to NPK.

6.3.3. Validation and Evaluation of the CSM-CERES Millet Model for Sotuba and Cinzana

The model adequately simulated the grain yields. The linear regression of simulated versus observed grain yield for Sotuba location genotype CHO (0.98 and 0.88) and SANIONI (0.96 and 0.92) for 2013 and 2014 respectively. While in Cinzana location, genotype SOSAT (0.68 and 0.99) and IBV8001 (0.91 and 0.96) for 2013 and 2014 respectively. The correlation had intercepts not significantly different from zero and the slopes not significantly different from one ($P > 0.05$).

The analysis coefficient of determination (R^2) showed that the value of R^2 for all genotypes grain yields are most often, within the acceptable limit ($R^2 > 0.5$). The values of R^2 for all genotypes indicated that a good correlation exists between the observed and simulated yields (Figure 6.7 a, b, c and d). The highest grain yield observed corresponded to the highest grain yield simulated and vice versa. It so happened for the corresponding measures taken for both simulated and observed.

Figure 6.7 shows that for the 2 years' period of experimental results for 2013 and 2014 in the in the two sites, the DSSAT models caught yields variabilities for different genotypes. Therefore, when analyzing year by year, a very good correlation was found in Sotuba location with (R^2=0.98 and 0.88) for CHO genotypes and SANIONI (R^2=0.96 and 0.92) in 2013 and 2014 respectively. The same case was found in Cinzana location with genotype Sosat (R^2=0.68 and 0.99) and IBV8001 (R^2=0.91 and 0.96) in 2013 and 2014 respectively. Therefore, in both years and among genotypes and each location the model performance (R^2) was high and there was a systematic overestimation of millet yield. But with SOSAT genotype (R^2) there was a difference between the two years, in 2013 which was in the acceptable range while for 2014 the yields were overestimated. This could be explained by the relatively even rainfall distribution throughout the season in 2013 and 2014, when very erratic rainfall patterns were observed with heavy downpours alternating with long early cessation or dry spell of rains (Traoré *et al.,* 2010). The same authors found out that, these discrepancies in the performance of the model could be explained by the poor assessment of the soil and crop water status during the reproductive and maturation phases. Therefore, sensitivity analysis showed that the response of the model is quite dependant on parameters such as runoff coefficients, rooting depth and soil water holding capacity, none of which were measured during our experimental trials.

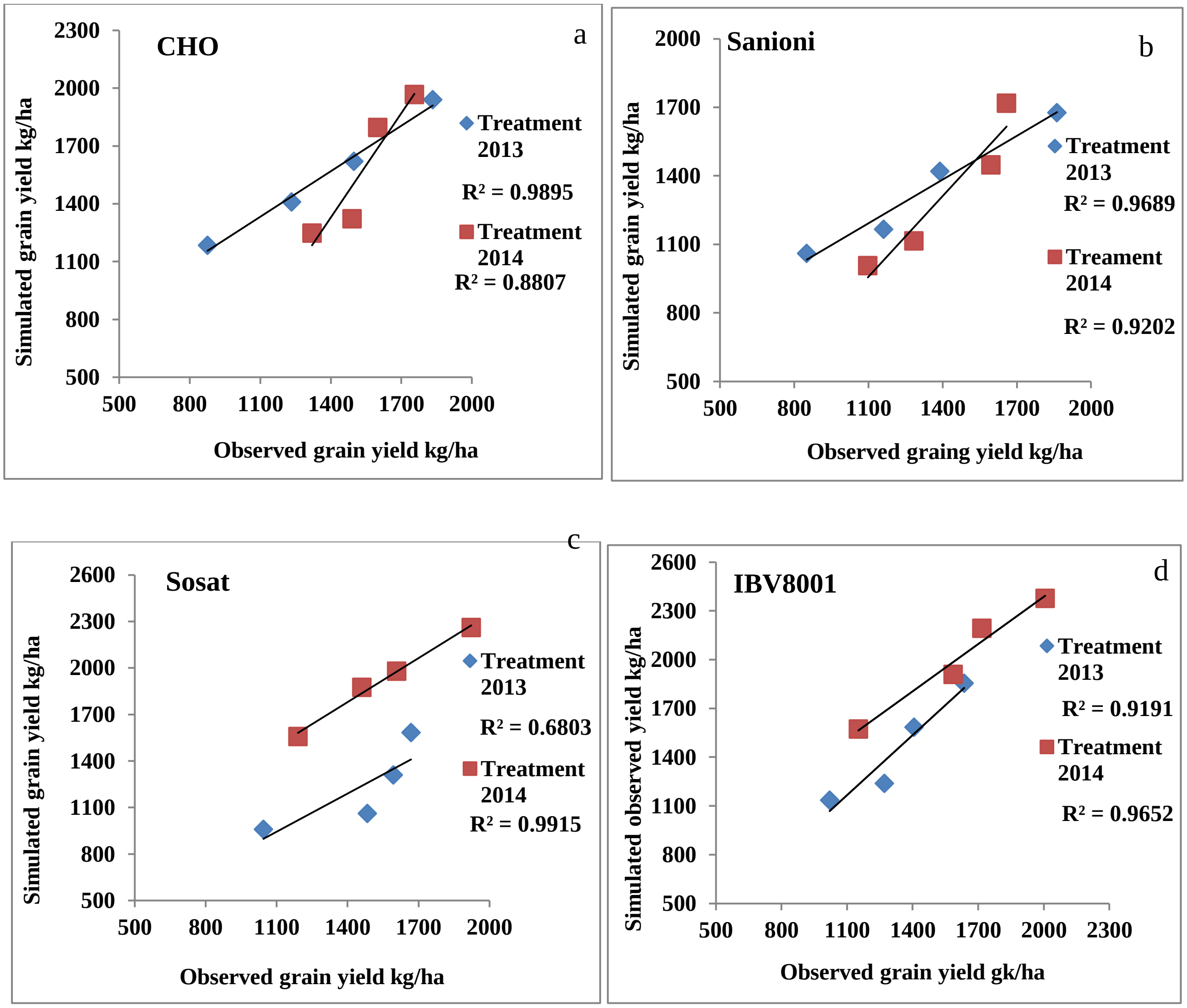


Figure 6. 7 Comparison between simulated and observed grain yields for Sotuba (a and b) and Cinzana (c and d) location with different varieties

Table 6.6 showed the values of root mean square error (RMSE) of Cinzana location for the grain yield for SOSAT and IBV8001. For the experimental year 2013 and 2014 for varieties SOSAT and IBV8001 the RMSE were (19.9 and 16.9 %) and (11.3 and 19 %), respectively. The overall percentage value of model efficiency above 50 % indicated good model performance thus for SOSAT and IBV8001 in 2013 (14.4 and 51.9 %) and 2014 the model efficiency (50.0 and 41.1%) indicated an overall good model performance for the Cinzana location.

Table 6. 6 Statistical parameters of simulation performance for the Cinzana location

Years	Varieties	RMSE %	Model Efficiency (%)
2013	Sosat	19.9	14.4
	IBV8001	16.9	51.9
2014	Sosat	11.3	50.0
	IBV8001	21.1	41.1

Sotuba location (Table 6.7) shows the values of root mean square error (RMSE) for the grain yield for SANIONI and CHO for the experimental year 2013 and 2014 for varieties SANIONI and CHO. The RMSE was (19.4 and 20.0 %) and (16.6 and 20.3 %) for 2013 and 2014, respectively. The overall percentage of model efficiency value above 50 % indicated good model performance thus for SANIONI and CHO in 2013 (85.3 and 14.4 %) and 2014 the model efficiency (70.1 and 68.9 %) indicated an overall good model performance for Sotuba location.

Table 6. 7 Statistical parameters of simulation performance for Sotuba location

Years	Varieties	RMSE %	Model Efficiency (%)
2013	Sanioni	19.4	85.3
	Cho	20.0	14.4
2014	Sanioni	16.6	70.1
	Cho	20.3	68.9

Based on the regional climate change conditions of the two agro-ecological zones, pearl millet has been simulated using DSSAT crop model. The results showed that the simulated achieved higher potential yield compared to the observed yields. The statistical parameters (Table 6.6 and 6.7) suggest that overall performance of the DSSAT model in the simulating chemical and organic fertilizer amendments under rainfed pearl millet production is good and able to project grain yields with high accuracy. And the analyses indicated good model performance. Therefore, with regards to agronomic conditions for the observed experiments and simulated situation cannot make a one to one mapping possible, then it can be argued that the value RMSE and model efficiency indicate good model performance. However, for the perfect models, a 100 % value should be observed for model efficiency. Higher percentage values indicate good model performance, thus the results of the model efficiency for Sotuba and Cinzana indicate an overall good model performance for all varieties.

Since the DSSAT was run using real field conditions, hence, it does not account for yield loss caused by harvest practices, diseases and pest and birds attacks; it can then be concluded that variations between observed and simulated is sufficiently accounted. The yield differences can also be attributed to soil types and degradation caused by unsustainable agronomic practices. However, the same approach was found in a study on rice simulation done by Oteng-Darko *et al.* (2012) where good correlation was found between observed and simulated yields with an average relative difference of 12.28 (<30 %).

6.3.4 Simulated millet grain yield under climate variability over 1983 – 2012 in Sotuba and Cinzana

Since the model is able to give good simulation of millet grain yield for all the treatments at both site for both varieties, the grain yields were simulated for the period 1983 - 2012 under historical weather conditions. High variability was observed in the grain yield over the past 30-years simulation period for all the treatments (Figure 6.8). For both sites and all varieties, the trend of simulated grain yields was Control < MANURE<NPK<MANURE+NPK. Furthermore, the lowest grain yields varied between 200 and 300 kg whereas the highest values were about 1500 and 2250 kg for Sotuba and Cinzana, respectively.

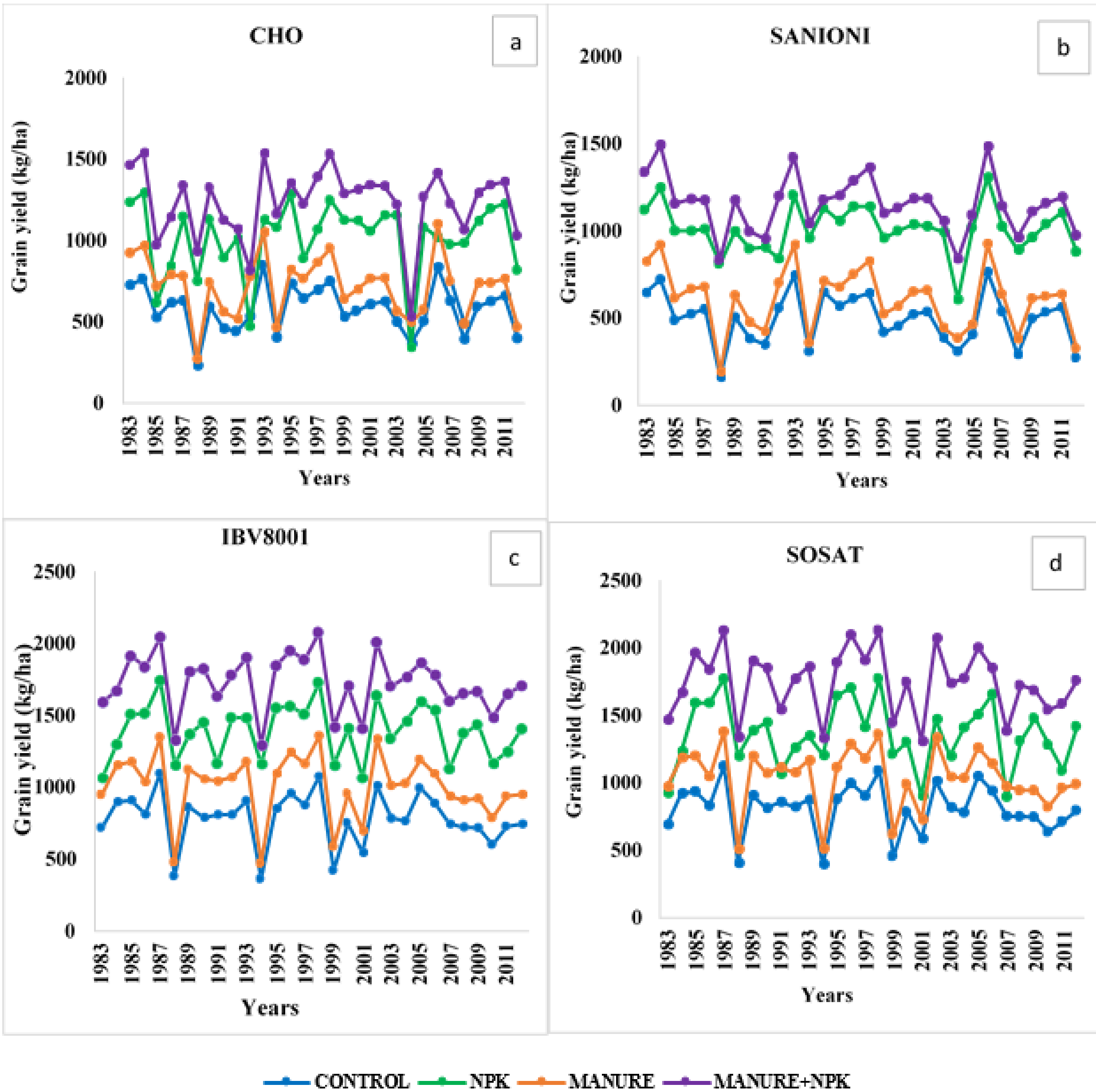


Figure 6.8. Simulated millet grain yield under historical weather data for Cinzana (a and b) and Sotuba (c and d)

The study first established where and how much crop yield varied with the varieties and then identify how much of the year to year variation in crop yields with the different treatment was explained by year to year variation in the climate. In general, the coefficients of variation (CV) or yield variability normalized by mean yields were lower in Cinzana with IBV8001variety under

NPK and MANURE+NPK treatments by 14 and 12 %, respectively. Similarly, the CV for SOSAT variety were 18 and 14 %, respectively with the same treatments at the same site (Table 6.8). As far as Sotuba is concerned, CV were slightly higher for CHO variety with CV of 23 and 18 % under the NPK and MANURE+NPK treatments, respectively. However, SANIONI variety showed low variability (14 % for both) under the same treatments (Table 6.9). Conversely, higher variability was found in Control and MANURE in both locations and both varieties. Higher CV (30 % for both treatments), which indicates the greatest variability in millet grain yield, were observed in Sotuba with SANIONI variety under Control and MANURE treatments (Table 6.9). Globally, the highest yield variability was found in Sotuba experimental site.

The results showed that millet yield responded to the different historical climatic conditions under all treatments. In line with the experimental observed data, the highest historical grain yields were achieved when the combination NPK +MANURE was applied. This shows the beneficial effect of combined application of organic and mineral fertilizer inputs the integrated soil management for Lixisol soil fertility. The relative increase in yield by NPK+MANURE combination application could be attributed to improvement in soil structure, nutrient retention and water for plant use (Arunah *et al.,* 2006). The study showed how much of the year-to-year variability in crop yield was associated with climate variability within the study areas. As reported by Tingen *et al.,* (2008) in Cameroon, this study also found that millet yield variability was explained only by a complex relationship between both temperature and precipitation variability. In conjunction with fluctuation in agricultural production as affected by climate variability, low food stocks can particularly contribute to changes in food price. Also location with high crop yield variability would disproportionately contribute to this effect especially if it is also the major granary. In Mali, semi-arid to arid conditions are depend with seasonal rainfall distribution. The study showed that an important climatic feature which is high annual variability in grain yield in Sotuba (Sudanian zone) than Cinzana (Sahelian zone). However, this may explain that the actual effect on millet grain yields variability depend on the agro-ecological zones for the specific crop and management approach. Pearl millet is more adapted in the Sahelian zone than the Sudanian zone.

Table 6.8. Historical average crop yields and coefficient of variation in Cinzana

	IBV8001			
	Control	NPK	Manure	Manure+NPK
Mean	784	1391	1010	1726
stdev	182	192	228	202
CV (%)	23	14	23	12
	SOSAT			
Mean	808	1357	1039	1743
stdev	182	243	225	242
CV (%)	23	18	22	14

Table 6.9. Historical average crop yields and coefficient of variation in Sotuba

	CHO			
	Control	NPK	Manure	Manure+NPK
Mean	580	1015	717	1232
stdev	144	231	187	222
CV (%)	25	23	26	18
	SANIONI			
Mean	496	1011	607	1154
stdev	146	138	183	162
CV (%)	30	14	30	14

6.3.5. Effect of climate change scenarios on millet grain yield for Cinzana and Sotuba

Simulation of climate change effects on millet grain yield showed that all scenarios underestimated crop yield compared to the Baseline for all treatments and both varieties in Cinzana (Figure 6.9a and b). For the variety IBV8001, the Control and MANURE treatments had the lowest grain yield (< 1000 kg/ha) whereas NPK +MANURE and NPK yielded over 1000 kg/ha. Crop yield under the

Control and NPK treatments were closer among the scenarios and compared to the Baseline. However, the outputs for all the scenarios under NPK+ MANURE and MANURE were very low compared to the Baseline, which reached about 2000 kg/ha. As indicated in Table 6.10, ANOVA test and LSD confirmed the significant differences ($P < 0.05$) between the scenario outputs under all treatments. Among all scenarios, ACCESS1-0 (Hot-Wet) showed the lowest grain yields under the four treatments (Figure 6.9a). The percentage of grain yields decrease as simulated by the scenarios varied between 3% for the Control and NPK under CMCC-CMS, and 24% for Manure under ACCESS1-0 (Figure 6.10a). Slight increase of 1 % was observed for the NPK treatment under CESM1-BGD.

Regarding the SOSAT variety, all the scenarios for the four treatments estimated low grain yield compared to the Baseline, except Control and NPK for which the CMCC-CMS (Cold-Dry) and CESM1 -BGC (Hot-Dry) yielded higher than Baseline for lower probabilities (Figure 6.9b). Similar to IBV8001 variety, all the scenarios under NPK+ MANURE and MANURE simulated very low grain yields compared to the Baseline. The lowest grain yields were of 200 kg/ha for Control and MANURE, and 900 kg/ha for NPK and NPK+ MANURE. ANOVA test and LSD revealed the significant differences ($P < 0.05$) among the scenario outputs for Control, NPK+MANURE AND MANURE (Table 6.10). Meanwhile, no significant difference was observed among the average grain yields for all the scenarios under NPK treatment. Similar to IBV8001 variety, SOSAT showed lowest grain yields under the four treatments for ACCESS1-0 (Hot-Wet). The grain yields decrease reached a percentage of 1% for the NPK under CCSM4, and 40% for Manure under ACCESS1-0 (Figure 6.10b). Increases of 1 to 5 % were observed for the NPK and Control under CMCC-CMS, CESM1-BGD and MRI-CGCM3.

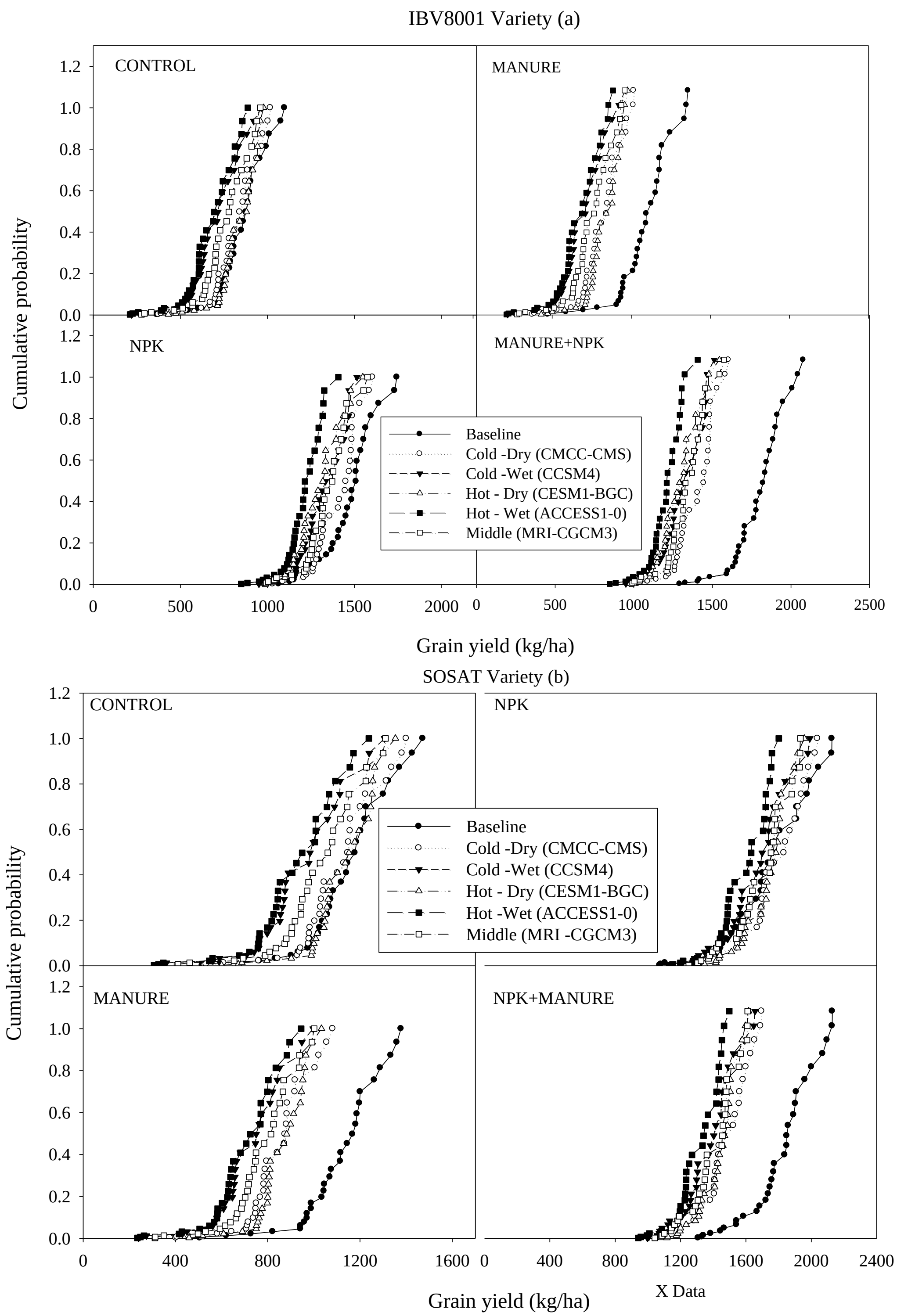


Figure 6.9 a and b. Effect of climate change scenarios on millet grain yield for Cinzana

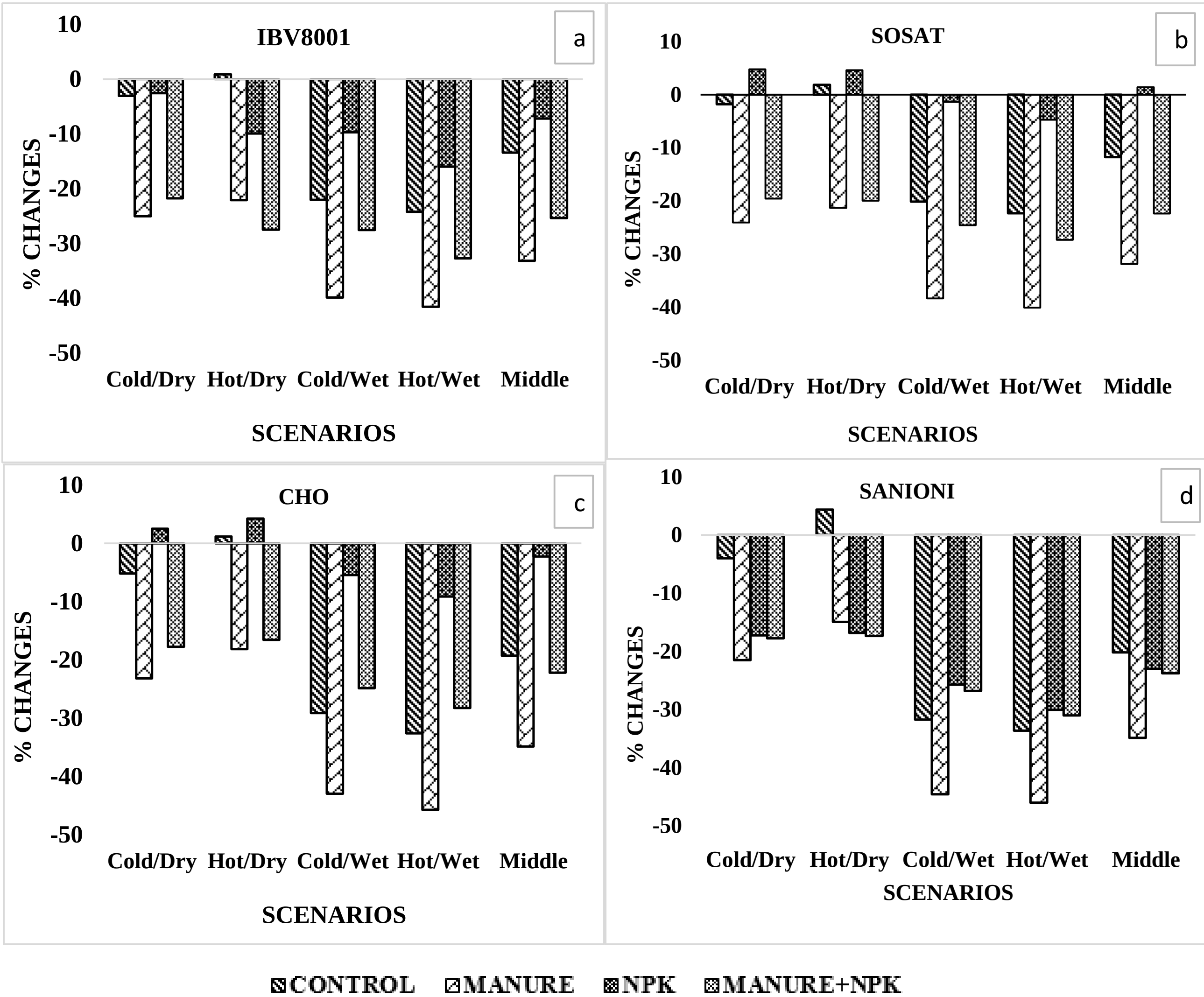
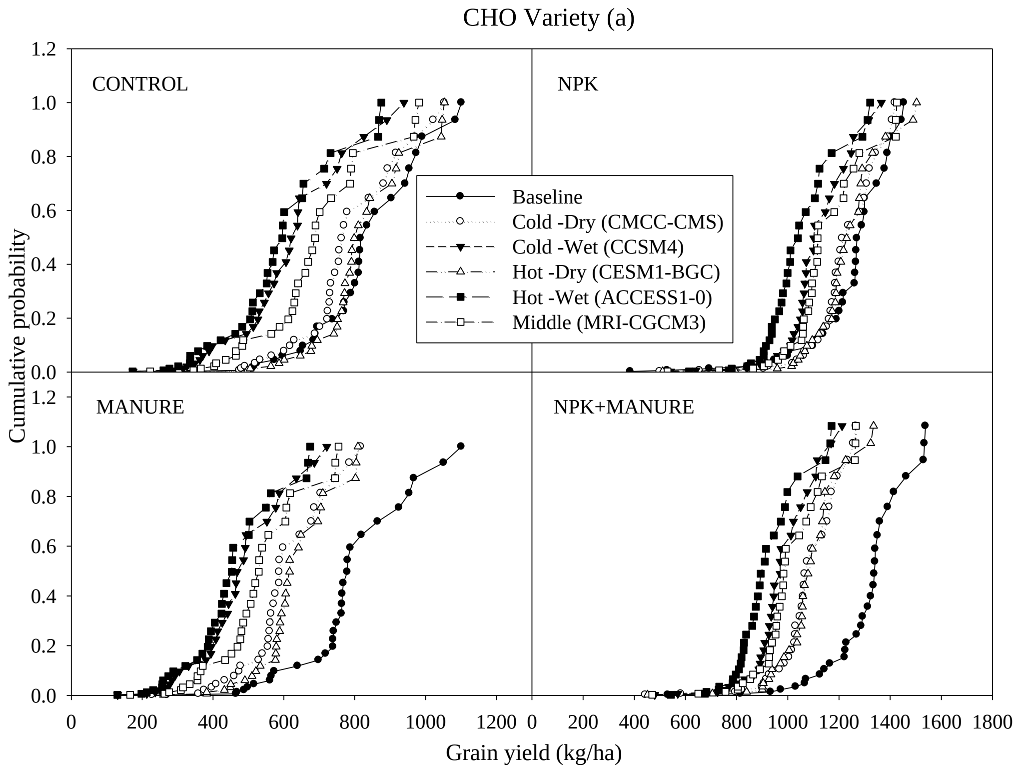


Figure 6.11 Percentage Changes of Millet Grain Yields for Cinzana (a and b) and Sotuba (c and d) under Different Scenarios

Similar to Cinzana site, simulation of climate change effects on millet grain yield in Sotuba, showed an underestimation of crop yield for all scenarios compared to the Baseline for all treatments and both varieties (Figure 6.10a and b). For CHO variety, all the scenarios for the four treatments estimated low grain yield compared to the Baseline, apart from Control and NPK for which the CMCC-CMS (Cold-Dry) and CESM1 -BGC (Hot-Dry) yielded higher than Baseline for very low probabilities (Figure 6.10a). NPK+ MANURE and MANURE simulated extremely low grain yields compared to the Baseline. The lowest grain yields were of 150 kg/ha for both Control and MANURE, and about 400 kg/ha for both NPK and NPK+ MANURE. Similar to IBV8001 variety in Cinzana, ANOVA test and LSD revealed significant differences ($P < 0.05$) among the scenario outputs for all treatments (Table 6.11). Meanwhile, CHO variety showed lowest grain yields under all treatments for ACCESS1-0 (Hot-Wet). The decrease in grain yields reached a percentage of 2% for NPK under MRI-CGCM3, and 46% for Manure under ACCESS1 -0 (Figure 6.10c). NPK and Control under CMCC-CMS and CESM1-BGD induced increases in grain yields by 1 to 4%.

As far as SANIONI variety is concerned, all the scenarios and treatments estimated low grain yield compared to the Baseline, apart from Control and NPK for which the CMCC-CMS (Cold-Dry) and CESM1 -BGC (Hot-Dry) showed higher grain yield than Baseline for very low probabilities (Figure 6.10b). MANURE+NPK and MANURE simulated under all the scenarios very low grain yields compared to the Baseline. The lowest grain yields were about 100 kg/ha for both Control and MANURE, and about 600 kg/ha for both NPK and NPK+ MANURE. For scenario ACCESS1-0 (Hot-Wet), SANIONI variety showed lowest grain yields under all treatments. ANOVA test and LSD revealed significant differences ($P < 0.05$) among the scenario outputs for all treatments (Table 6.11). Simulations for the Control under CMCC-CMS, and MANURE under ACCESS1 -0 decreased by 4 % and 46%, respectively (Figure 6.10d). Control under CESM1-BGD induced increases in grain yields by 4%.



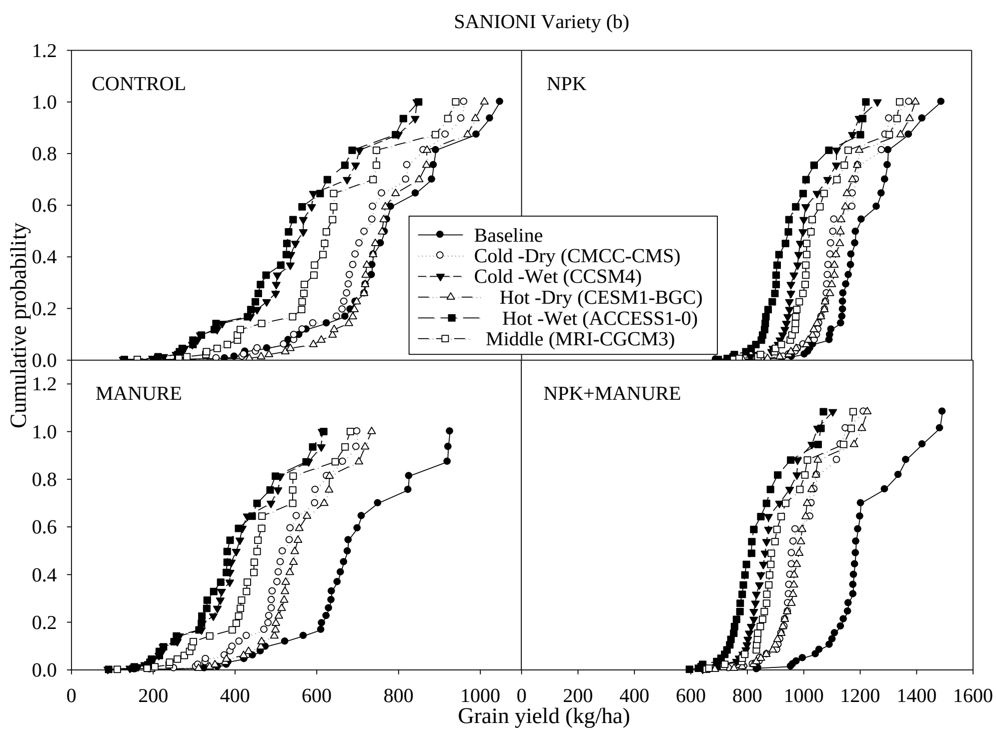


Figure 6.10a and b Effect of climate change scenarios on millet grain yield for Sotuba

Table 6.10 Changes in grain yields for different climate scenarios and treatments in Cinzana.

IBV8001				
	CONTROL	MANURE	NPK	MANURE+NPK
Scenario	Mean	Mean	Mean	Mean
Baseline	784±182 A	1009±228 A	1390±192 A	1726±2-2 A
Cold/Dry	757±167A	754±168 BC	1344±151 AB	1343±151 B
Hot/Dry	624±190 B	620±190 CD	1250±162 BC	1246±163 BC
Cold/Wet	778±142 A	775±142 B	1237±145 BC	1236±145 BC
Hot/Wet	605±179 B	601±179 D	1158±133 C	1154±134 C
Middle	685±180 AB	681±179 BCD	1281±156 AB	1278±156 B
P-value	0.000	0.000	0.000	0.000
SOSAT				
	CONTROL	MANURE	NPK	MANURE+NPK
Scenario	Mean	Mean	Mean	Mean
Baseline	808±182 A	1038±25 A	1356±243 A	1743±242 A
Cold/Dry	787±168 A	785±169 BC	1398±191 AB	1394±190 B
Hot/Dry	655±193 B	651±193 CD	1313±187 AB	1309±187 BC
Cold/Wet	808±141 A	805±142 B	1386±145 AB	1383±145 BC
Hot/Wet	635±183 B	631±183 D	1260±158 B	1256±158 C
Middle	714±180 AB	711±180 BCD	1346±174 AB	1343±173 BC
P-value	0.000	0.000	0.051	0.000

Table 6.10 Changes in grain yields for different climate scenarios and treatments in Sotuba

SANIONI				
	CONTROL	MANURE	NPK	MANURE+NPK
Scenario	Mean	Mean	Mean	Mean
Baseline	496±146 AB	606±184 A	1170±211 A	1153±162 A
Cold/Dry	471±128 AB	470±130 B	952±114 B	947±118 B
Hot/Dry	347±140 C	345±140 C	854±104 C	845±109 C
Cold/Wet	507±120 A	505±122 AB	956±118 B	951±121 B
Hot/Wet	337±136 C	335±136 C	804±117 C	796±121 C
Middle	400± 141 BC	399±142 BC	887±124BC	880±128 BC
P-value	0.000	0.000	0.000	0.000
CHO				
	CONTROL	MANURE	NPK	MANURE+NPK
Scenario	Mean	Mean	Mean	Mean
Baseline	580±144 A	717±186 A	1015±231 A	1231±221 A
Cold/Dry	548±132 A	547±134 B	1017±179 A	1012±180 B
Hot/Dry	419±142 BC	417±143 C	930±155 AB	920±157 BC
Cold/Wet	580±126 A	578±127 B	1028±171 A	1023±172 B
Hot/Wet	399±141 C	397±141 C	881±139 B	873±142 C
Middle	473±144 BC	472±144 BC	962±169 AB	954±170 BC
P-value	0.000	0.000	0.007	0.000

. Figures 6.9 (a and b) and Figures 6.10 (a and b) showed the simulated effects of the scenarios of rainfall and temperature changes on millet grain yields for the period 2040 to 2069. The changes are computed as averages across the 29 GCMs simulations for each agro-ecological zone. Future climate projections from GCMs showed decreasing millet grain yields over 2040 – 2069 compared to the Baseline period (1983 – 2012) at both sites. Simulations showed higher grain yields under historical weather data compared to the situation with the changing climate future scenarios. The study showed that an increase in temperature and precipitation would be the main unfavourable driver of the future change in pearl millet yields. The effects of climate change and variability are more acute in the Sudanian zone for both varieties and treatments. This may be explained by the fact that in the Sudanian zone, a semi-arid area with mean annual rainfall between 800 - 1100 mm, the increase in temperature in that among of rainfall may provoke excessive and useless soil moisture damageable to pearl millet production. These findings are consistent with previous studies for sorghum using another crop model (Sultan *et al*., 2014) and also for millet and sorghum (Sultan *et al.,* 2013) and for maize (Schlenker and Lobell, 2010). All these findings confirmed that temperature increase is the main driver decreasing the yield for future climate change. Higher temperatures generally decrease the yield by increasing the plant growth rate, reducing thus the period available for biomass production (Chmielowski *et al.,* 2004; McCarthy *et al.,* 2012).

Furthermore, the result showed that millet grain yields respond positively i.e. an increase of grain yield under CMCC-CMS and CESM1-BGC scenarios than the three others. The increase in grain yield for those scenarios were observed under the Control and NPK treatments. This may be explained by the fact that in CMCC-CMS, the increase in temperature by 1.4° C and no change in rainfall may not affect the grain yields under Control and NPK treatments. Similarly, increase in temperature by 2.4° C and 10 % decrease in rainfall (CESM1-BGC scenario) may also not affect the grain yield. Millet yield decreased significantly under climate change scenarios, particularly under NPK treatment and the ACCESS1-0 scenario, which is based on increase of both in temperature and precipitation (2.4° C and 30 %, respectively) for the period 2040 - 2069. As indicated in previous researches (McCarthy et al 2010; Eyshi Rezaie et al., 2013), this may be due to the high average temperature and the short phenological phase duration of pearl millet, especially in critical growth stages such as grain filling period under mineral fertilisation. The frequency of extreme events like warm day and warm night could therefore affect the productivity of millet in the Sudanian and Sahelian zones. In addition, excessive rainfalls (about 30 % in this study) can have severe impacts on millet production through the reduction of nutrient availability due to soil loss and fertilizer leaching.

6.4 Conclusion

In conclusion, the study found that DSSAT model is a good crop modelling for selection of crops, soil and management options to suit the semi-arid and arid zone in Mali. The crop model showed good performance in reproducing the pearl millet yields to climatic variables under present treatment applications. It is able to capture the grain yield under different historical climate condition and also under different future climate conditions. Whereas in the future scenarios the simulation showed an excessive decreasing of grain yield. All the varieties showed lowest grain yields under the four treatments for ACCESS1-0 (Hot-Wet) among the scenarios

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This section of the study summarise the main findings of the study as presented in previous chapters and further develop necessary recommendations for farmers, policy makers and other Stakeholders.

7.2 conclusions

Based on the findings of this study, effect of climate change and variability on pearl millet (*Pennisetum glaucum* (l.) R. Br.) Production in the Sudanian and Sahelian agro-ecological zones in Mali, the study concluded that:

Farmers in Cinzana commune are conscious and aware of climate variability and change and see it as a real risk to their livelihood. A number of different strategies have been adapted by farmers in response to environmental degradation as a result of climate change impact. Perceptions of farmers of climate variability are in line with climatic data records. Indeed, farmers in Cinzana were able to recognize reduction of rainfall. The study found that the use of improved crop varieties was the main adaptation strategy among farm adaptation strategies in Cinzana because yield can be increased through improved crop management. Gender, size of land and age of household head were the significant determinants of adaptation strategies. The study analysed some factors likely to be influenced by climate variability and change in the study area. From the correlation analysis, it was revealed that factors such as household size, gender, education, age and farm size were statistically significant in relation to the adoption of strategies to mitigate climate change. The study analysed changes in precipitation and temperature extreme indices in Sotuba and Cinzana based on daily maximum and minimum temperature indices and precipitation series for the period from 1961 to 2014. The data were controlled and data series were homogenised using the software RClimdex 3.2.0. The finding of the study showed that there is a general decrease in the cold nights (TN10p) and cold days (TX10p) in Sotuba, while Segou showed high decreasing trend. A general warming trend in the temperature indices for warm nights (TN90p) and warm days (TX90p) since 1961 were observed. Although, there was a general tendency of decreases in annual total rainfall, the observed trends are not as uniform as the one in temperature. The observed trends have an implication on the economies of the two regions most of which are not strong enough to mitigate climate effects. Therefore, the warming trend observed means a higher demand on domestic energy consumption for cooling, higher evaporation rates from water bodies and irrigated crops, and a lower performance from livestock and agricultural crops. Furthermore, older persons are particularly vulnerable to such increase in temperature and may increase the level of mortality. Elsewhere, increased frequencies of extreme rainfall events such as long dry or wet spells mean weaker productive systems. Despite the small number of homogenous temperature and rainfall indices series, the study could represent a proportion of significant extremes in Ségou station average trends. The study provides evidence that during the last 53 years, Ségou was particularly affected by warm extremes based on night time indices rather than cold extremes based on day time indices.

The low productivity of millet crop in the Sahelian and Sudanian zones is caused by poor soil fertility due to uncertain rainfall conditions. A research trial addressed the issue to alleviate the agricultural production constraints with variable results depending on the agro-ecological environment and years. The results of the present study showed that millet production could be improved further by combining inorganic fertilizers with the placement of manure. The highest grain yield was obtained in straw yield and grain yield by OM+NPK combined application and the control as expected obtained the lowest yield. The output of this study clearly showed that module DSSAT simulated millet crop growth and yield with good accuracy. However, studies have indicated crop simulation models as potential decision making agronomic tools to understand millet crop bio-dynamism under variable climatic conditions of agriculture. Moreover, the model evaluation over the two agro-ecologies enhances our knowledge to build resilience in various situations and to pick variability and rainfall regimes, prove a better tool for crop yield and rainfall forecast of the regions. The statistical parameters suggest that the overall DSSAT performance model in simulating chemical and organic fertilizer amendments in rainfed and irrigated maize is good and able to predict biomass and grain yields with high accuracy. The study showed that increase in temperature and precipitation in future would affect millet grain yield in climate.

7.3 Recommendations

This section outlines recommendations based on the outcomes of the study. The study acknowledges the extent of research on climate change that has been done across Africa, and a number of recommendations have therefore been made to policy makers to address climate change issues. There has been limited research on the subject of study in the selected study area and it's therefore important to provide the necessary recommendation to help in mitigating climate change and its impact in these areas.

It is therefore recommended that researchers, policy makers and the necessary institutions educate and provide information to farmers in order to enable them better understand climate change and its impact on their farming activities so as to adopt the necessary farming practices to mitigate these challenges. It is further recommended that researchers must design programmes that build on farmers' perceptions and plan climate awareness campaigns. Policy makers should also purpose at strengthening institutions such as meteorological services and agricultural extension so as to give real time information on climate change to farmers. Moreover, further studies must explore the role issues play in intensifying climate change impact and their subsequent effects on farmers.

Policies relating to climate change are most often country or regional specific however, this study has demonstrated the need for a more tailored policy for specific geographical areas, it is therefore recommended that policy and decision makers must draw up policies for specific areas that have greater impact of climate change.

There is no doubt of global warming especially during day time and the frequency of night days' increase in temperature over the period 1961 – 2014 for the two agro-ecologies zones of Mali. In the current study, trends in extreme temperature and rainfall were established from historical climate data for two meteorological stations. Further research work could improve the value of the current finding by analysing climate data from more stations, especially selected from and representing the entire two natural regions in Mali. The findings could contribute to Geographical Information Systems (GIS) and provide information into the remapping and reformulation of farming recommendations in the natural regions. However, for agriculture, research for more heat resistant crops, animal species and cultivars should be promoted. Also the production systems need to be changed to reduce higher risks of crop losses due to climate change

Based on the simulation results from this study, the DSSAT crop model is suitable to simulate the impact of climate change on millet yield for the conditions in the two agro-ecological zones. However, the model performance in simulating on a long term basis needs to be further evaluated. From the point of view of information generation, DSSAT model will be able to explore climate change effect on plant and yield growth of another important cereal crop namely, pearl millet in future. This crop is presently better suited to the drier regions. The model can be used for management, planning and operation of irrigation projects for efficient use of water. The model can simulate and compare crop yield under different climate scenarios and cropping system, for instance, intercropping, rotation and sole cropping. Therefore, simulated crop yield for smallholder farmers under climate change could be fed into economic models to estimate the economics of climate change implications for instance losses or/and gains. These subjects hold potential for further research.

APPENDIX

Questionnaires for evaluating farmers' perceptions of climate change and their adaptation strategies and evaluate change in land use, especially cropped areas and yields.

Region *Department*: **Commune:**

Village

SECTION A GENERALE INFORMATION

I- SOCIO-ECONOMIC CHARACTERISTICS OF HOUSEHOLDS

1- Sexe : M ☐ **F**

2- Ethnie et nationalité/ Ethnic group/nationality

Bamanan ☐ Senoufou ☐ Maninke ☐ Peulh ☐ Autres ☐ Preciser…………

Etrangers/ *foreign* ☐ Précisez………………………..

3- Dans quelle tranche d'âge vous situez-vous?/ *Age*

18 à 35 ans/ *years old* ☐ De 35 à 55 ans/ *years old* ☐ De 55 ans et plus/ *years old and more* ☐

4- Statut matrimonial/ *Marital status*

Marié(e)/ *married* ☐ Célibataire/*single* ☐ Veuf/ *widow* ☐

Monogame/ *monogamous* ☐ Divorce/ *divorced* ☐ polygyne/ *polygamous* ☐ Nombre de femmes/ Number of wives

5- Confession religieuse/ *Religion*

Chrétien/ *Christian* ☐ Musulman/ *Muslim* ☐lythéïste/ *Polytheist* ☐
Autres/ *Others* ☐ Précisez/ *specify*…………………….**.**

6- Statut social du chef de ménage/ *Household's head*

Chef de cours ☐ chef de famille ☐ chef de quartier ☐ Notable ☐

Chef religieux ☐ Chef de communauté ☐ Autres ☐ Précisez/ Spefify………………..

7- Niveau d'instruction/ *Education level*

Illettré/ *illiterate* ☐ Primaire/ *primary level* ☐ Secondaire/ *secondary level* ☐
Supérieur/ ☐

8- Revenu mensuel du chef de ménage/ *Household's income*

Moins de/ *less than* 50 000F ☐ De*/ between* 50 000F à 99 000F ☐
De/*between* 100 000F à 149 000F ☐ De/*between* 150 000f à 199 000F ☐
De/ *between* 200 000F à 299 000F ☐ Plus de/*more than* 300 000F ☐

9- Avez-vous une activité secondaire ou disposez-vous de revenus additionnels/ *Do you have a second activity? Or other sources of income*?

Oui/ yes ☐ Non/ no ☐

Si oui, laquelle?/ *if yes, name it*……………………

A combien pouvez vous estimer ces revenus par mois/ *What is your income for this activity* ?........................

10- Que faites-vous en dehors de cette activite / *What are the other activities*?

Peche/ *fishing* Artisanat/ *local craft* Cueillette-chasse/*hunter-gatherer*
Elevage/livestock Autres/ *others*

…………………………………………………………………………………………………

Pourquoi/ *why* ?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………………………

11- Taille du ménage (nombre de personnes habitant la maison)/ *size of the household (number of people)*

Moins de/ *less than* 05 ☐ entre/ *between* 05 et 09 ☐ entre/ *between* 10 et 14 ☐
entre/*between* 15 et 19 ☐ *more than* 20 et plus ☐

II- CARACTERISTIQUES DES ACTIVITES AGRICOLES/ *FARMING ACTIVITY CHARACTERISTICS*

12- Quand avez-debute votre activite agricole / *When did you start farming* ?

Depuis au moins 30 ans/*years* 30 et 20 ans/*years* 20 et 10 ans/*years*
10 et 5 ans/*years* moins de/ *less than* 5 ans/years

13- Quelles sont les cultures que vous pratiquez / *What crops do you cultivate* ?

☐ ☐ ☐

Riz/ *rice* Mil/ *Millet* Sorgho/ *Surghum* ☐ Coton/Cotton

Autres/*others* (préciser/Specify *name then* ☐

…………………………………………………………………………………………………

14- Combien de champs ou de parcelles possedez-vous/ *How many farms do you have* ?

…………………………………………………………………………………………………

15- Quelle est la superficie totale de votre champ/ *What is the total area of your farmland* ?

Moins de/ *less than* 1 ha ☐ de/ *from* 1 - 2 ha ☐ de/ *from* 3 - 5 ha ☐

de/ *from* 6 - 10 ha ☐ plus de/*more than* 10 ha ☐

16- Depuis combien de temps cultivez_vous en continue ce champ? / Since when have you been cultivated this farm ?

…………………………………………………………………………………………………

17- Quelle est la rotation culturale que vous pratiquez dans votre exploitation? /What is the cultural rotation what you pratice in your farm ?

…………………………………………………………………………………………………

18- Est-ce que vous faites la jachère? / Do you do fallow land ?

…………………………………………………………………………………………………

19- Si oui quel est l'âge de la jachère ? / If yes what is the age ?

…………………………………………………………………………………………………

Moins de 05 ☐ entre 05 et 10 ☐ entre 11 et ☐ entre 21 et 30 ☐ 30 et plus ☐

20- Parmi ces cultures, quelle est celle qui vous procure le plus de satisfaction/ *Among your crops, which one give you more satisfaction*?

………………………………………………………………………………………………..

21- Pourquoi/ *why* ?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………

SECTION B: AGRICULTURAL PRODUCTION/ *PRODUCTION AGRICOL*

22. What are the priority crops grown now and 30 years ago?/ Quels sont les priorites

Crop grown currently		Crops grown 30 years ago		
Crop grow now/ *culture cultive maintennt*	How important is the crop for food security (see code below)/ *Quelle importance à la culture pour la securite alimentaire (voir code dessous) par ordre d'importance*	Crop grown five years ago/ *culture cultive il ya 5ans*	How important was the crop for food security (see codes below /*Quelle importance a la culture pour la securite alimentaire (voir code dessous)/*	If there is a change in priority of crop, why?/ *S'il ya changement dans ces dites cultures, pourquoi?*

Codes for importance of crop 1=Very importance 2=Moderate importance 3=Not important

23- Pendant combien de mois dans l'année votre exploitation agricole n'est pas autosuffisante ?/ *How many months in the year your farm is not self-sufficient*

……………………………………………………………………………………………………

24. What are the indicators of a good crop production year? *Quels sont les indicateurs d'une bonne annee de production?*

Indicator (e.g rainfall)/ *Indicateur*	Description/ *Description*

25.In the last 10 years, which years would you consider as having been good? *Quel annee a ete bonne après 10 ans passes?*

……………………………………………………………………………………

26. What are the indicators of a poor crop production year? *Quels sont les indicateurs d'une mauvaise annee de production?*

Indicator (e.g rainfall)/ Indicateur	Description/ Description

27. What are the average yields for the following major crops in a good crop production year and a poor crop production year? ***Quel sont les rendements moyennes pour les cultures majeur d'une bonne et mauvaise annee de production?***

	Home field		Out field	
Crop/*Culture*	Amount in kg/acre in a good crop production year/ *le montant de kg/hectare d'une bonne annee de production*	Amount in kg/acre in a bad crop production year/ *le montant de kg/hectare d'une mauvaise annee de production*	Amount in kg/acre in a good crop production year/ *le montant de kg/hectare d'une bonne annee de production*	Amount in kg/acre in a bad crop production year/ / *le montant de kg/hectare d'une mauvaise annee de production*
Maize/ Maise				
Millet/ Mil				
Sorghum/Sorgho				
Groundnuts/Arrachide				
Cowpea/ Haricot				
Bambara nut/				
Other 1				
Other 2				

29. In the last 10 years, what has been the change in production of the following crops?/ ***Quel a ete les changements dans la production de ces cultures après 10ans passes?***

………………………………………………………………………………………………

How would you rank the changes you have mentioned above in terms of their contribution to change in agricultural productivity? *Comment notez vous le changement que vous avez mentionnez pour la contribution du changement de la productivite agricole?*

Cause of decline in crop production/ *Cause de la baisse dans la production des culture*.	Rank these factors starting with 1= most critical and 2= very most critical/ *Notez ces facteurs commencant avec 1= plus critical et 2= tres tres critical*

30. What are the main changes that you have made in the way you farm in the last ten years? /*Quels sont les principaux changements que vous avez effectues dans la facon don't vous cultivez au cors des 10 dernieres annees.*

a) Things that you are doing now that you were not doing before, varieties? Techniques culturales, engrais, herbicidage?/ *Choses que vous faites maintenant que vous ne faisiez pas avant, les variétés? Techniques culturales, engrais, herbicidage?*

Changes/ *Changements*	When did you make the changes?/ *Quand est ce vous avez fait les changements*	Why did you make the changes?\ *Pourquoi avez vous fait les changements*

b) Things that you were doing before and have now stopped, varieties? Techniques culturales, engrais, herbicidage? / *Choses que vous faites maintenant que vous n'avez arrte pas avant, les variétés ? Techniques culturales, engrais, herbicidage?*

Changes/ *changements*	When did you make the changes? /*Quand aviez vous les changements*	Why did you make the changes?/ *Pourquoi vous avez fai les changements*

SECTION C. HOUSEHOLD INCOME AND CAPITAL ASSETS/ *REVENU DES MÉNAGES ET IMMOBILISATIONS*

31. What are your main sources of income in the past year and how important are these sources to your livelihood? *Quelles sont vos principales sources de revenu de l'année écoulée et quelle sont l'importances de ces sources à votre vie?*

Income Source/ *Source de revnue*	Yes/ *No*	Priority/ *Priorite*
Sale of crop/ *vente de culture*		
Sale of livestock/ *vente de betail*		
Informal work(maricho)/ *le travail informel (maricho)*		
Formal employment/ *le travail formel*		
Remittances/ *versement de fonds*		

Old age pension/ *la pension de vieillesse*		
Pension fund from workgift received in kind/ *fonds de pension de recompense de travil recu*		
No income at all*/ aucun revenu*		
Gardening/ *gardinage*		
Others (sepecify)/ *autre (preciser)*		

Codes: Yes=1. No= 2/ Codes: Oui = 1, NO = 2

28. What livestock do you own?/Quels betails avez vous?

Assets/Biens	**Do you own?/ *Avez vous?*** 1= yes/*oui* 2=no/*non*	**If yes, how** many?/ Si oui, combien?	**Source:/ *Source*** 1=bought,/*achete* 2=gift,/*cadeau* 3=inheritance,/*heritage* 4=other source/*autre source*	**Purpose for keeping/*But de leur garder*** 1=Mainly for food/*essentielement pour nourriture* 2=Mainly for cash/ *essentiellement pour l'argent* 3=Equally for cash and food/*pour l'argent et nourriture* 4=For asset accumulation / prestige/*Pour accumulation ou prestige*
Cattle/*Boeuf*				
Goats/sheep/ *chevre, mouton*				
Poultry/*volaille* (chickens/*poule, Guinea* fowls/*pindade,* donkey/*ane*)				
Pigs/ *cochon*				
Others (specify)/*autre*				

29. What major agricultural assets/implements do you have? /*Quel outillage majeur vous avez?*

Asset/*Bien*	Do you own/*Avez vous*	Number/*Nombre*	Source:/ *Source* 1=bought/ *achete,* 2=gift/*cadeau,*

	1= yes/*oui* 2=no/*non*		3=inheritance/*heritage*, 4=other/*autre Source*
Ox-drawn plough/ *Charrue de boeuf*			
Harrow/ *herse*			
Ridging plough/ *pulverisatoire*			
Oxcart/ *char a boeuf*			
Sprayer/ *pulverisateur*			
Cultivator/ *cultivateur*			
Hoes/ *houe*			
Irrigation equipment (e.g. treadle pump, water pump, etc)/ *materiel d'irrigation (pompe a eau)* Other/*autre*(specify)………………….….			
Planter/ *planteur*			
Ripper/ *eventeur*			
Axe/ *axe*			
Other/ *autre* (specify) ……………………			

30. What major domestic assets do you have?/*Quels sont les biens domestiques que vous possedez?*

Assets/Biens	Do you own?/*Avez vous?* 1= yes/*oui* 2=no/*non*	If yes, how many?/ *Si oui, combien?*	Source:/*source* 1=bought,/*achete* 2=gift,/*cadeau* 3=inheritance,/*heritage* 4=other source/*autre source*
Bicycle/*Bicyclette*			
Sewing machines/ *machine a coudre*			
Radio/TV/*Radio/ TV*			
Mobile phone/*telephone portable*			
Watch/clock/*horloge*			
Paraffin stove/ *rechaud a petrole*			
Other/ *autre* (specify)			

SECTION D: FARMER PERCEPTIONS OF CLIMATE CHANGE/ *PERCEPTION DES PAYSANS SUR LE CHANGEMENT CLIMATIQUE*

31. Are you aware of climate change? If yes/ ***Etes-vous conscient du changement climatique? Si oui***

……………………………………………………………………………………………………..

31. Have you noticed any significant changes in weather patterns over the years in relation to agriculture? 0= No, 1= Yes/ ***Avez-vous remarqué des changements significatifs des conditions météorologiques au cours des années par rapport à l'agriculture? 0 = Non, 1 = Oui***

32. For the changes mentioned above, what are some of their impacts in your household, the environment etc?

33. If any of these occurrences happens what actions do you take related to agricultural

production?

34. Do you have access to the weather forecasting data/information? 0=No, 1=Yes

If yes, what different kinds of information do you get and where do you get it from?

Type of information	Source of information 1=Radio, 2=Extension 3=Fellow farmer 4=Television 5=other (specify)

35. How would you rate the weather information that you receive?

	Rating 1=Poor, 2=Average 3=Good	What are the reasons for your rating?	What are your suggestions for improvement?
Timlineness			
Adequacy			
Frequency of dissemination			
Usefulness			
General content			
Delivery channel			
Language of presentation			

36. If the forecast information is positive i.e it predicts that the rainfall will be enough and will be on time, what are some of the actions that you take in your farm?

Action	Do you take this action? (tick if farmer mentions)	Why do you take this action?

37. If the forecast information is negative i.e it predicts that the rainfall will not be good or reliable, what are some of the actions that you take in your farm?

Action	Do you take this action? (tick if farmer mentions)	Why do you take this action?

38. Do you have any traditional / indigenous ways of predicting the weather patterns?

Weather pattern	Prediction Indicators
Drought Year	
Normal year (Rainfall)	
Flood Year	
Very cold winters	
Normal winters	
Very hot summer	
Normal summer	

39. What are the trends that you have observed in the following in the last ten years?

Variables	Increased (tick)	Same (tick)	Declined (tick)	What would you say is the main causes of this change?
Crop yields				
Crop types, varieties				
Crop pests and diseases				
Livestock populations				
Livestock diseases				
Quality of pastures				
Rainfall amounts				
Water availability (for				
Soil erosion				
Wind erosion				
domestic use)				

Food availability for household consumption				
Water erosion				
income from agriculture				

40. For those variables where there has been a change, how are you coping with these changes?

Variables	How are you coping with change?
Crop yields	
Crop types, varieties	
Crop pests and diseases	
Livestock populations	
Livestock diseases	
Quality of pastures	
Rainfall amounts	
Water availability	
Soil erosion	
Water erosion	
Wind erosion	
Income from agriculture	
Food availability for household consumption	

41. Are you using any of the following farming practices in your farm as a result of the changes inn weather patterns?

Farming practice	Do you use? ((Tick as if farmer mentions)	When do you use? 1=All the time 2=During drought years 3=During good rainfall years
Potholing		
Ripping		
Crop residues		
Chemical weed control		
Tied ridging		
Winter ploughing		
Conservation basins		
Using drought tolerant varieties		
Changing crops		
Mulching		
Intercropping		
Mono cropping		

Fallowing		
Other		

42. Are there some crop production practices that you use in good rainfall years and avoid in drought years? If yes, which ones

Cropping practice	Do you use in good rainfall years? 0=No 1=Yes	Do you use in drought years? 0=No 1=Yes	Reasons
Use of fertilizers			
Use of cattle manure			
Hire of labour for farming activities			
Use of irrigation			
Purchase of improved seeds			
First weeding			
Second weeding			
Other specify			

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