ECONOMIC IMPACT ASSESSMENT OF CLIMATE CHANGE ON AGRICULTURE IN BURKINA FASO: A RICARDIAN APPROACH

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The authors would like to thank the Global Environment Facility/World Bank for financial support, and the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria and the Yale University team for technical support. We extend our particular gratitude to Pradeep Kurukulasuriya of Yale University for technical assistance with data and analysis (development of the model underlying this work). We are also grateful to James Benhin, Arial Dinar, Robert Mendelsohn, Samia El-Marsafawy and Samiha Ouda for comments on earlier drafts of this paper.

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Correct citation: Ouedraogo M, Somé L & Dembele Y, 2006. Economic impact assessment of climate change on agriculture in Burkina Faso: A Ricardian Approach. CEEPA Discussion Paper No. 24, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Core funding for CEEPA comes from the University of Pretoria. CEEPA receives supplementary funding from various donors including the Swedish International Development Cooperation Agency (SIDA), GEF, NRF South Africa, NOAA (USA), IDRC.

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ISBN 1-920160-24-8
First published 2006
Series ISBN 1-920160-01-9

Printed and bound in South Africa by University of Pretoria

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

This study aims to assess the impact of climate change on agriculture in Burkina Faso. It uses the Ricardian cross-sectional approach to measure the relationship between climate and net revenue from growing crops. It regresses the net revenue of crops on several variables: climate, soil, relevant hydrology and socio-economics. It tests three models (one without adaptation, one with adaptation and one with a dummy zone variable). From the estimated models, we determine the marginal climatic effects and their elasticity in order to examine the sensitivity of net revenues from crops to temperature and precipitation. The study determines how Burkina Faso farms would respond to climate change based on the Intergovernmental Panel on Climate Change scenarios (IPCC) and scenarios of the hydrology component of the GEF/World Bank Project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*. The IPCC scenario is a uniform scenario that predicts a uniform change of temperature in Africa. It makes it possible to compare the effects in the countries involved in the GEF/WB project. The scenarios of the hydrology component of this project are specific to each country. The study's findings of the study give a lot of information about the sensitivity of agriculture in Burkina Faso to climate variables.

The marginal effect of temperature on revenue is 19.9 US$/ha and the marginal impact of precipitation on revenue is 2.7 US$/ha according to the adaptation model at all farms level. This means that if the temperature increases by 1°C, revenue will fall by 19.9 US$/ha. If precipitation increases by 1 mm/month, net revenue increases by 2.7 US$/h. The elasticity shows that agriculture is very sensitive to precipitation in Burkina Faso. For example, an increase in temperature of 5°C (IPCC scenarios) will be very harmful for agriculture: farms would lose 93% of their net revenue from crops. Farms would also lose their entire net revenue from crops if precipitation decreased by 14%. The scenarios of decreasing rainfall and increasing temperature are critical for crop yields because Burkina Faso's climate is already hot and dry.

The study reveals that some variables used in the regression can be effective as adaptation options. Extension service and irrigation are significant and positively affect net revenue. The study does not capture the full dimensions of climate change impacts in Burkina Faso, but constitutes an important start in understanding how climate change will affect crop yields and how farmers will respond to the change.

1. Introduction

In Burkina Faso agriculture dominates the economy. It employs 86% of the total population (estimated at 12.1 million in 2003). About 40% of GDP comes from agricultural activities (crops 25%, livestock 12% and forestry and fishing 3%), which are the main sources of the county's economic growth.

Burkinabe agriculture is a subsistence agriculture based on cereal growing (sorghum, millet, maize, fonio[2] and rice) which take up 88% of the cultivated area per year and constitute the staple diet of the majority of the population. Cotton is the main export crop and provides on average 50% of export income. Burkinabe agriculture is almost exclusively extensive and not highly productive. Its development is hampered by major natural constraints (climatic factors and soil degradation).

The country lies in the Sudano-Sahelian zone, where the climate and natural environment are harsh. The rainfall is low and characterized by strong inter-annual and space-time variability. This directly affects agro-pastoral production. At present there is a tendency to aridity in the north, causing a decrease in the crop growing period of 20 to 30 days, and a displacement of the isohyets towards the south as compared to the 1960s. A succession of droughts has modified the natural environment and caused desertification.

The soils are generally not very deep, with low water retention capacity and low organic matter content. They undergo water and wind erosion in the Sahelian zone and are becoming exhausted, causing a decrease in yields in the central plateau area where the population is concentrated. Natural resources are becoming further degraded from year to year because of traditional farming methods and population growth, notably near the urban centers.

These physical and climatic constraints make Burkinabe agriculture vulnerable, as crops are essentially rainfed. Vulnerability due to climatic hazards, the inadequate growth of productivity and the poor diversification of incomes are the reasons why economic and food insecurity persist in the rural households. The climatic hazards which affect the stability of agro-pastoral production and export incomes are weakening the country's economy. The fragility of the economy will be exacerbated by global climate change because Burkina Faso's economic performance closely depends on the agricultural sector's performance.

According to the Intergovernmental Panel on Climate Change (IPCC), the average global temperature on the surface of the earth increased by about 0.6°C during the 20th century and since 1950 there is likely to have been a decrease in the frequency of extremely low temperatures as well as a rise, more modest, in the frequency of extremely high ones. The IPCC also estimates that precipitation increased during the 20th century by 0.5% to 1% every ten years in most of the high and middle latitudes of the continents in the northern hemisphere and from 0.2% to 0.3% in the tropical land areas (10° north to 10° south). But rains decreased in the subtropical land areas of the northern hemisphere (10° North to 30° North) during the 20th century by about 0.3% every ten years.

The climatic changes which have taken place at the regional level, especially the increase in temperatures, have already seriously affected the physical and biological systems. The human systems – agriculture, forestry, fishing and so on – will be affected as well. Because the

[2] A cereal crop grown in light soils and not needing particular care.

climatic conditions set the limits for agricultural methods, any change will have obvious effects on the agricultural ecosystems and the average outputs (in time and space).

The effects of these climatic changes are therefore inevitable and raise the question of how farmers can adapt. The literature shows there are technical, financial and management adaptation options available to them, such as changing crops, modifying the farming calendar and farming methods, improving techniques for water and irrigation management, and so on. Farmers' ability to adapt depends on factors such as wealth, technology, education, information, competence, infrastructure, access to resources and management abilities. It is also strongly influenced by the level of vulnerability of the ecosystems.

Burkina Faso will be particularly strongly affected. The fragility of its environment on the one hand and its low level of technological and economical development on the other make it unable to develop and pay for suitable adaptation strategies. The country is therefore particularly keen to be informed about the possible disastrous effects of climatic change on agricultural production and about suitable adaptation measures for reducing them.

This study forms part of the GEF/World Bank Project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*. Its objective is to evaluate the impact on climatic changes on agricultural production in Burkina Faso.

The study's aims are

- to apply the Ricardian approach to assess the extent of the relationship between agricultural income and climate variables;
- to determine the marginal impact of temperature and precipitation on agricultural income;
- to evaluate the effect of climate change on revenue on the basis of the IPCC climatic changes scenarios and the results of the hydrological component of the GEF project; and
- to recommend strategies for adapting to climate change.

Section 2 which follows describes Burkina Faso's physical environment (geography, soils and climate) and the characteristics of its agriculture (production systems and the importance of agriculture in the economy). Section 3 reviews the literature on approaches for the assessment of impacts on agriculture with emphasis on the Ricardian method. Section 4 presents the methodology of the study. It describes how the Ricardian approach was adapted for the analysis in this study, and the modeling approach (definition of the functional form of regression models, definition of variables and hypotheses, explanation of the estimation procedure. Section 5 presents the results of the estimated regression models (interpretation of the coefficients and analysis of the marginal impacts). Section 6 presents the predictions of how climate change will affect Burkina Faso's agriculture. Section 7 describes farmers' perceptions of and adaptations to climate change, and finally Section 8 concludes and discusses implications for policy.

2. Geography, climate and agriculture in Burkina Faso

2.1 Geography and physical framework

Burkina Faso is a landlocked country in West Africa covering about 274,000km². It extends between 9°20' and 15°05' latitude north, 5°20' longitude west and 2°03' longitude east and is surrounded by the Republic of Mali in the north and west, Cote d'Ivoire in the south-west, Ghana, Togo and Benin in the south and Niger in the east.

The hydrographic network of Burkina Faso is quite dense, but most of the rivers are not permanent, which limits the possibilities of irrigation. The natural vegetation is composed of steppe in the north, shrubs and annual grasses in the center and various trees and perennial grasses in the south and the south-west (Guinko 1984). The relief is relatively flat, with an average altitude of 400m. But this overall flatness does not exclude some variety: altitudes vary from 125m in the south east to 749m in the south-west (Tenakourou). The genesis and nature of the rocks make it possible to distinguish two main topographic domains: (i) a peneplain which occupies three-fourths of the country, lying on volcanic and metamorphic rocks with a crystalline structure, and (ii) a sandy solid mass in the south-west made up of sedimentary rocks.

We can distinguish eight main groups of soils: i) tropical ferruginous soils, less leached or leached, on sand-clayey or clay-sandy materials, which cover more than one-third of the country; ii) underdeveloped soils, with erosion, on gravel materials and alluvial deposits, which cover about a quarter of the country; iii) raw mineral soils which are poor, shallow and found on bed-rock or ferralitic pans, and not suitable for cultivation; iv) mineral hydromorph soils with pseudomorphic material of various textures; v) burnished soils on clayey materials; vi) vertisols; vii) sodic soils with varying texture and degraded structure; and viii) ferralitic soils, which are less disaturated, on sandy-clayey materials. The most common soils (39%) are ferruginous tropical less leached to leached soils (luvisols and lixisols). Others types of soils are fluvisols and regosols (26%); ferralitic soils, which are rather rare, chemically poor with reduced organic matter; brownish-red sandy-clay soils with low organic matter contain; alluvial soils, clayey or loamy and generally deep; and vertisols.

The soils have a low level of fertility (a very low rate of nitrogen (N) and phosphates (P)) with a limited water holding capacity (BUNASOLS 1985, Dembélé & Somé 1991). Most are characterized by their structural fragility, which makes them easily degradable when farmed. It is obvious from these conditions that the effect of soils on income will be negative.

2.2 The climate

Burkina Faso has a dry tropical climate. The dry season is characterized by the harsh harmattan winds which blow from the north-east to the south-west from October to March. April is the month of humid winds or trade winds bearing monsoons. The rainy season, from May/June to September, is characterized by humid winds.

Over the whole country, the seasonal rainfall is monomodal. The mass of humid air of Atlantic origin goes up the Gulf of Guinea and reaches Burkina from the south-west where the rains start in April. At first sporadic, they gradually cover the whole country from June onwards. August is the wettest month for the whole country. The rains cease from the end of September. October is when the dry harmattan winds blow.

The duration of the rainy season decreases progressively from the south-west to the north. The rainfall is very erratic and its volume also decreases from the south-west to the north. There are large seasonal variations in temperature and high ranges at night, particularly in the north of the country (Some & Sivakumar 1994).

The country is divided into three zones according to the climate (Figure 1). These agro-climatic zones constitute the phyto-geographical units of the country:

- The south Sudanese zone, situated south of the 11°30' parallel with an average annual rainfall between 900 and 1200 mm. The rainy season here lasts six months. This is the domain of gallery forests along the rivers.

- The north Sudanese zone, situated within the 11°30' and 14°00'N parallels. This zone has an average annual rainfall of between 800mm and 900mm during four to five months. Here there are more dense woody formations, and the herbaceous cover is more continuous. This is the largest zone and the one which is most affected by human activity.

- The Sahelian zone, situated north of 14°00'N. This zone has an average annual rainfall of between 300mm and 600mm concentrated into three months. The vegetation here consists of steppes with trees, shrubs and thick bushes.

Figure 1 show the agro-climatic zones. The isohyets are calculated on the basis of rainfall data from 1970 to 2000. The geographical limits of these agro-climatic zones fluctuate with the climatic drift which has become stressed since these recent decades. This fluctuation is illustrated by Figures 2 and 3. Figure 2 shows the position of the isohyets calculated on the basis of the average precipitation for the period 1950–1980 and Figure 3 shows the new position of the isohyets calculated on the basis of the annual precipitation for the period 1970–2000. We can observe that the isohyet 1200mm has disappeared in the south of Burkina Faso whereas the isohyet 400 mm appears in the north of the country (Figure 3). This situation confirms that the climate has changed in Burkina Faso.

2.3 Agriculture in Burkina Faso

Agriculture and farming systems

Around 30% (10 million hectares) of the soils are suitable for crop production in Burkina Faso. Of this potential, only one third (3,500,000 hectares) is actually cultivated per year. The main crops are as follows.

Cereals: These account for nearly 88% of the annual cropped area. In order of importance these are sorghum (white and red), millet, maize, rice and fonio. Cereal crops are mainly rainfed and therefore exposed to the climatic risks and the continuous degradation of the soils and environment. Rice is the principal irrigated cereal. Recently, the government has been promoting small scale irrigation in the dry season for maize and cowpeas (*niébé*). Because the population depends on cereals as the staple food, Burkina Faso imports more or less significant quantities of cereals. For instance, 50% to 60% of rice is imported yearly.

Legumes and tubers: These are mainly cowpeas, bambara groundnuts, sweet potatoes, yams and to a lesser extent cassava. They are grown on a very small percentage of the land (2% of cultivated surfaces in 2002–2003).

Cash crops: The main export crops are cotton, sesame, groundnuts and soybeans. These use only 12 % of the annual sowed surfaces.

Vegetables and fruit: The main vegetables and fruits grown are tomatoes, onions, cabbage, okra, green beans, potatoes, mangoes, citrus and bananas. Tomatoes are still the primary market oriented vegetable, but production is hampered by some post-harvest problems (packaging, stocking and transport). Only green beans and mangoes are exported to the European Union. Market gardening is practiced in large irrigation schemes but also in small individual vegetable gardens. The latter generate extra income for farmers and this has positive effects on the trade balance.

Figure 4 shows the distribution of crops throughout the country. The south Sudanese zone (particularly the western region) presents a more diversified agriculture than the rest of the country. All the crops grown in Burkina Faso are found in this region. It has a cereal production surplus which it exports to the rest of the country and to neighboring countries. It provides more than 90% of the country's cotton. It also has immense potential for livestock farming and has become notable for agro-pastoral production. The Sahelian zone (north) only has crops which do not need much water, such as millet and cowpeas. Pastoral livestock farming is established in this zone. The north Sudanese zone has an averagely diversified agriculture with a predominance of sorghum and millet.

Agriculture in Burkina Faso is dominated by the rainfed system. About 24,000ha are irrigated for an irrigable potential of 160,000ha including 130,000ha under partial water control and 30,000ha under full water control. The irrigated crops are rice, sugar cane and vegetables.

In Burkina Faso agriculture is almost exclusively extensive. It is mainly practiced on about 800,000 small scale family farms of three to six hectares. It is a food crop agriculture, with low productivity and dependent on climatic hazards. In these conditions crop production can hardly satisfy food needs and guarantee food self-sufficiency.

Importance of agriculture in the economy

The economic and social development of Burkina Faso is mainly based on the agriculture, which occupies nearly 86% of the working population and contributes 30% of the GDP.

Cotton is the country's primary export product: it accounts for about 50 to 55% of incomes and more than two and a half million people earn a living from it. Burkina Faso also exports shea nuts and cashew nuts. About 404 million CFA francs worth of shea nuts were exported in 1995 and 498.8 million CFA francs worth in 1996 (INSD 2000).[3]

Livestock contributes approximately 10% to the GDP and employs around 6% of the active population. It is the second source of income after cotton.

[3] One US dollar = 500 CFA francs.

Importance of agriculture as the primary sector in the economy

Agriculture in the form of crop production, livestock breeding, fishery and forestry is the primary sector of the economy, accounting for nearly 40% of Burkina Faso's GDP, and ensuring employment and income to about 90% of the active population and guaranteeing around 80% of total exports.

From 1994 to 2004, this sector contributed up to 38.23% to the GDP, compared with 19.09% for the secondary sector and 42.68% for the tertiary sector. During this period, its contribution to the GDP rose by about 1.3%, after the boost from cotton farming. Figure 5 illustrates the sector's relative contribution to the GDP. It should be pointed out that the activities of the secondary and tertiary sectors depend to a large extent on the activities of the primary sector, for example in the case of cotton and grain production, which is processed and transported by the secondary and tertiary sectors. The primary sector's activities thus have a ripple effect on the rest of the economy. The whole GDP develops according to the rhythm of the primary sector.

3. Review of literature on approaches used to assess impact of climate change on agriculture

Several methods have been developed to estimate the impact of the climate on agriculture. These methods can be grouped in two main categories (Bazzaz 1997): the structural modeling of the agronomic response based on controlled experiments (the *production function* approach), and modeling taking into account the link between crop production and the farmers' economic management decisions, based on theoretical specification (the *Ricardian* approach).

3.1 The production function approach

This approach is based on the existence of a production function for each crop, which links its yield to the physical, biophysical and biological environment. Among the environmental factors which affect crop yield, climate is the most important. Former bioclimatic studies, undertaken by agricultural research teams, highlighted the determining role of some climatic factors such as the availability of rain water, the degree of heat, the sun's radiation, the evaporation capacity of the air, the air's CO_2 content etc. This approach directly estimates the variation in the crop yield using a crop response model. It measures the impact of the studied factor by using different application levels. Many studies have used this approach to evaluate the impact of the climate on crop production, for example Reilly et al.(1994), Rosenzweig and Iglesias (1994) and Rosenzweig and Parry (1994). Rao and Sinha (1994) used this method to assess the impact of the climate change on wheat production In India. More recently, Kumar and Parikh (2001) evaluated the impact of climate modifications on rice and wheat by using this method.

This approach can assess the impact of low to very low factor variations; however it overestimates the damage to crop yields due to climate change. Mendelsohn et al. (1994), call this bias as the 'dumb farmer scenario', in other words, it does not take into account farmers' adaptations as a response to social, economic and environmental changes. Indeed, most of the studies using this model do not take into account farmers' adaptations but simply assess one or several factors involved in crop yield. The Ricardian approach, however, compensates for the bias in the production function approach.

3.2 The Ricardian approach

The Ricardian approach is a cross-sectional model applied to agricultural production. It is based on land rent which is seen as the net revenue from the best use of land. The land rent reflects the net productivity of farmland. Farm value (*V*) consequently reflects the present value of future net productivity. The principle is captured in the following equation (Mendelsohn & Dinar 2003):

$$\begin{aligned} V &= \int P_{LE} e^{-\delta t} dt \\ &= \int \left[\sum P_i Q_i (X, F, Z, G) - \sum RX \right] e^{-\delta t} dt \end{aligned} \qquad (1)$$

where:

P_{LE} = net revenue per hectare

P_i = market price of crop i

Q_i = output of crop i

F = vector of climate variables

Z = set of soil variables

G = set of economic variables such as market access and access to capital

X = vector of purchased inputs (other than land)

R = vector of input prices

t = time

δ= discount rate

The farmer is assumed to choose *X* to maximize net revenues given the characteristics of the farm and market prices. The Ricardian model examines how a set of endogenous variables, *F*, *Z* and *GI*, affects farm value. The model is based on the observed response of crops and farmers to varying climate, i.e. it uses actual observations of farm performance in different climatic regions (Mendelsohn et al. 1994; Ouedraogo 1999). Specifically, the method examines farm performance across different agro-climatic zones. It measures how long-term farm profitability varies with local climate, while controlling for other factors.

The standard Ricardian model relies on a quadratic formulation of climate:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u \tag{2}$$

where u is an error term and F and F^2 capture linear and quadratic terms for temperature and precipitation. The introduction of quadratic terms for temperature and precipitation respectively reflects the non-linear shape of the response function between net revenues and climate. From the available literature, we expect that farm revenues will have a U-shaped relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, but when the quadratic term is negative, the function is hill-shaped. For each crop, there is a known temperature where that crop grows best across the seasons though the optimal temperature varies from crop to crop (Mendelsohn et al. 1994). From Equation 2 we can derive the marginal impact of a climate variable (f_i) on farm revenue evaluated at the mean as follows:

$$E[dV / df_i] = E[\beta_{1,i} + 2 * \beta_{2,i} * f_i] = \beta_{1,i} \tag{3}$$

The change in welfare, ΔU, resulting from a climate change from C_0 to C_1 can be measured as follows (Kurukulasuriya & Mendelsohn 2006):

$$\Delta U = V(C_1) - V(C_0) \tag{4}$$

If the change increases net income it will be beneficial and if it decreases net income it will be harmful.

3.3 The Ricardian model specification for Burkina Faso

Following Mendelsohn and Dinar (2003) the empirical estimation of the Ricardian model for Burkina Faso extends the standard model given in the previous section (Equation 2) to capture the impact of water on farm value. According to Mendelsohn and Dinar (2003), water is already reflected in the Ricardian model, as it comes to farms in the form of precipitation. However, there are two additional sources of water, surface and ground water, that can be remote from the farm and climate at the farm may give little indication of the amount that is available from these two sources. To capture these additional sources of water, the empirical model for Burkina Faso introduces runoff as the other source of water (*W*) provided by the hydrology modeling for this study:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 W + u \tag{5}$$

where W is a vector of relevant hydrological variables that captures the sources of water other than precipitation, such as surface runoff. Inclusion of W allows for empirical tests of the relationship between farmland values *(V)* and other sources of water, such as surface and ground water. The study also tests the nature of the relationship – whether it is linear or quadratic.

4. Data and empirical models

4.1 Study sites and data

The data for the analysis is based on cross-sectional data on household and district level. These include farm household, climate, soils and hydrology data.

Farm household data were obtained from a survey conducted in 51 districts across the country. The survey covered all of the country's provinces, except for Kadiogo, which is the province of the capital city of the country. The surveyed districts were selected based on agro-climatic zones in order to capture the space distribution of the climatic variability across the country.[4] Figure 6 presents the distribution of the study sites. A sample of 1530 households were chosen according to the typology of the farms derived from the document of the economic accounts of the agricultural sector of Burkina Faso (see Table 1).[5] Table 2 summarizes the provinces and shows the number of households sampled in each province.

The data collected at household level was for the year 2002–2003, in particular the rainy season from May to October 2002 and the dry season from November 2002 to April 2003. The data include:

- the socio-economic characteristics of the agricultural households (household size, gender, ethnic group, religion, education level, etc.);

[4]There are three climatic zones in Burkina Faso and the country is divided administratively into 13 regions, 45 provinces and 351 districts (INSD 2000). The study unit selected is the department which corresponds to the district level. We made a stratified and reasoned sampling so as to take into account the administrative division and the agro-climatic zoning of the country. A random sampling approach was used to select sites from each Province. The province of Kadiogo was not taken into account because Kadiogo is the capital city of the country (with an urbanization rate of 75%). It is a sample province selection with the selection probability proportional to the importance of the number of districts. A proportional distribution of the number of sites per province was also carried out to give more weight to provinces that have a large area. Thus the largest provinces, (Gourma, Comoé, Kénédougou, Tapoa, Soum and Sissili) had two districts included in the sample, as compared with only one district for the other provinces.

[5] This typology is based on three criteria: farm area (in ha), household size, and modernity (level of equipment and use of chemical fertilizers). The area criterion identifies small (<3ha), average (3–5ha) and large farms (>5ha). The size criterion identifies small (<5 persons), average (6 to 9 persons) and large households (more than 10 persons). The modernity criterion identifies manual farms, animal traction farms and motorized farms with or without application of chemical fertilizers (table in appendix). Three types of agricultural households were retained per district, giving a total of 30 x 51 = 1530 households (Figure 6).

- the characteristics of the farms (cropland, farmland, type of crop, land ownership, etc.);
- the use of production factors (land, agricultural input, equipment and tools, draught animals, irrigation water, etc.);
- the use made of the produce (consumption, sale, losses); and
- the socio-institutional environment of the farmer (access to credit, access to subsidies, access to extension services, etc.).

The farm household survey provided the agricultural information for calculating net revenue as a proxy of farm values for the Ricardian analysis.

Climate data came from two sources. The satellite climate data come from the Department of Defense in the USA (Kurukulasuriya & Mendelsohn 2006). The satellites give surface temperature and surface wetness. The African Rainfall Temperature Evaluation System (ARTES) data come from the National Oceanic and Atmospheric Association's (NOAA's) Climate Prediction Centre of the USA (World Bank 2003). The ARTES data is based on ground station measurements of precipitation and minimum and maximum temperature.

Soil data were obtained from the Food and Agriculture Organization (FAO). The data provides information on major and minor soils by districts in the country (FAO 2003).

Hydrology data were provided by the International Water Management Institute (IWMI) and the University of Colorado, Boulder.

4.2 Empirical model

4.2.1 Functional form

According to the evidence of the results obtained by Mendelsohn et al. (1994) and Sanghi et al. (1998) in their studies, and taking into account the distinctiveness of the climate of Burkina Faso, we have opted for the follow functional form:

The model with without adaptation options includes only the physical variables (temperature, precipitation, runoff and soils):

$$\begin{aligned} NR_{ha} = {} & \beta_1 rainy\_st + \beta_2 rainy\_st^2 + \beta_3 dry\_st + \beta_4 dry\_st^2 + \\ & \beta_5 rainy\_artw + \beta_6 rainy\_artw^2 + \beta_7 dry\_artw + \beta_8 dry\_artw^2 + \\ & \beta_9 runoff + \beta_{10} runoff^2 + \sum_{i=1}^{n} \alpha_i Soil_i + C^{te} \end{aligned} \qquad \text{(Model1)}$$

Where: rainy _st and rainy_artw are the mean satellite temperature and the total ARTES precipitation of rainy season respectively, and dry _st and dry_artw are the mean satellite temperature and the total ARTES precipitation for the dry season respectively.

The model with adaptation model includes the previous variables and farms characteristics:

$$RN_{ha} = \beta_1 rainy\_st + \beta_2 rainy\_st^2 + \beta_3 dry\_st + \beta_4 dry\_st^2 +$$
$$\beta_5 rainy\_artw + \beta_6 rainy\_artw^2 + \beta_7 dry\_artw + \beta_8 dry\_artw^2 + \quad \text{(Model 2)}$$
$$\beta_9 runoff + \beta_{10} runoff^2 + \sum_{i=1}^{n} \alpha_i Soil_i + \sum_{j=1}^{m} \mu_j Z_j + C^{te}$$

The model with adaptation and zone dummy model includes the previous model and the zone dummy variables:

$$RNA_{ha} = \beta_1 rainy\_st + \beta_2 rainy\_st^2 + \beta_3 dry\_st + \beta_4 dry\_st^2 +$$
$$\beta_5 rainy\_artw + \beta_6 rainy\_artw^2 + \beta_7 dry\_artw + \beta_8 dry\_artw^2 + \quad \text{(Model 3)}$$
$$\beta_9 runoff + \beta_{10} runoff^2 + \sum_{i=1}^{n} \alpha_i Soil_i + \sum_{j=1}^{m} \mu_j Z_j + Zone\_dummy + C^{te}$$

With Zj the set of farm characteristic and socio-economic variables, β_j , α_j , μ_j are coefficients of the variables and C^{te} is a constant term.

The independent variables include the linear and quadratic terms of temperature, precipitation and runoff and only the linear terms of soils and farm characteristics.

4.2.2 Description of the variables

Dependent variable

This was calculated for each agricultural household and is defined as being the value of the crop production minus the associated production costs. Many types of incomes were calculated by integrating step by step the various production costs (such as transport, storage, auto-consumption, losses, fertilizers and pesticides, machinery, and manpower costs – household and hired labor'). This made it possible to use the most appropriate agricultural income for our study. This was the net income (nrUS3) defined by the difference between the value of the total crop and selected production costs. The costs of the household and hired labor were not taken into account for various reasons. Taking into consideration the household labor costs led to negative net incomes, which can be explained as the effect of overestimating the working hours – determining these is problematical in family agriculture. In the regressions, we have used proxy variables to control for labor. Figure 7 gives the average agricultural net incomes of the study sample according to the different definitions.

The incomes varied according to the agro-climatic zones (Figure 8). The north Sudanese zone, which is the most rainy, had the highest incomes (US$176/ha average). The Sahelian zone, which has a rainfall of less than 600mm, had the lowest (US$100/ha). The farms practicing irrigation had the highest incomes in the sample (about US$316/ha) (see Figure 9). Water is therefore a true income differentiation factor which was examined further in the three empirical models.

Explanatory variables

The explanatory variables include climatic variables, relevant hydrology variables, soil variables and farm characteristics.

Climatic variables: These are temperature and precipitation variables, based on satellite data for temperature (in degrees Celsius) and ARTES for precipitation (in mm/month).

The climatic data are reported for the rainy season, May to October, and the dry season, November to April. For each season we defined a temperature variable and a precipitation variable. Thus the dry season temperature variable corresponds to the average of the temperatures of the dry season (November to April), and the rainy season temperature variable corresponds to the average temperature of the rainy season (May to October). In the same way, the precipitation variable for the dry season corresponds to the average of the dry season's precipitation and the precipitation variable for the rainy season corresponds to that of the rainy season.

It is important to note that the farming calendar in Burkina is seasonal. Agricultural production, essentially rainfed, is carried out during the rainy season. However, during the dry season, irrigation (also called truck farming) is practiced, notably for vegetables and rice growing. These crops represent only a small proportion of the areas cultivated per year

Soil variables:

We identified 11 groups of soils: luvic arenosols (Ql), eutric gleysols (Re), solodic planosls (Ws), gleyic luvisols (Lg), ferric luvisols (Lf), phinthic luvisols (Lp), vertic cambisols (Bv), chromic cambisols (Vc), euric cambisols (Be), dystric nitosols (Nd), lithosols (I). Some soils have properties which can alleviate the effects high temperature and low rainfall have on the crops. The expected effect will depend on the type of the soil.

Farm characteristic variables

Factors which can explain the variability of agricultural incomes are the type of agricultural equipment and the level of intensification in production (land, water, work). For the level of equipment, we defined an animal traction variable (the use of plow and donkey or cow). For the production factors, we examined the effect of the total area farmed, the household size and the use of hired labor. These two last variables serve as proxy to the labor that is not taken into account in calculating the net income. The expected effect of these variables is positive.

We also examined the effect of extension on net revenue. Extension services promote the use of agricultural inputs (fertilizers, pesticides and improved seeds) to increase crop yield. The expected effect of these variables is positive.

Because agriculture in Burkina Faso is mainly rainfed and therefore exposed to climatic risks, irrigation can alleviate these risks. We therefore examined the effect of irrigation and runoff on net revenue.

We also examined the effect of livestock on crop revenue. (See Table 3 for descriptive statistics of all the variables.)

4.2.3. Estimation procedure

The three models were estimated using Stata statistical and econometric software. Different stages of the estimations were undertaken. At the first stage we integrated the climatic variables, then the hydrologic variables (relevant hydrology) and finally the soils. This first sequence of variables made it possible to define a model without adaptation relying only on physical factors (climate, runoff and soils).

At the second stage we integrated into the first model variables related to farm characteristics (household size, farmland, use of animal power, use of hired labor, livestock ownership) and the environment in which they evolve (access to extension service, practice of irrigation). This permitted us to take farmers' adaptations into consideration and to assess their effect on the agricultural income. This second stage led to the second model, with adaptation options. The third stage consisted of integrating into the previous model a dummy variable corresponding to the three agro-climatic zones of Burkina Faso (Sahelian zone, north Sudanese zone and south Sudanese zone). For each of the two last models, we also estimated separately for irrigated farms and dryland farms.

5. Results from the estimated model

5.1 Validation of the models

We have used the Fisher-Snedecor test to validate the total significance of the models and the Student test for the individual significance of each coefficient. The Fisher-Snedecor test shows that the 12 regressions are all significant at the 5% level.

The coefficient of determination (R^2) of the model without adaptation is 15.24%. The integration of adaptation variables improved upon the model (with R^2 =19.42%) with further improvements when the dummy for agro-climatic zones was included, an indication of the contribution of each agro-climatic zone to the variation in income.

The models relating to rainfed farming have a lower R^2 ranging around 17%. With a small number of irrigated farms in the sample, the estimated regressions for these were not significant. Many variables have been eliminated from the model and no coefficient is significant at the threshold of 5%. Whatever the model regressions estimated, a large part of the variation in the agricultural income remains unexplained by the variables taken into account.

5.2 Results of the regression models

Tables 4 to 6 present the results of the estimated models. The results show that the signs of seasonal climatic variables are the same for all the estimated models (model without adaptation, model with adaptation and model with zone dummy variables). The sign of quadratic terms is opposite to the sign of linear terms for the temperature and the precipitation. The relationship between revenue and temperature or precipitation is therefore non-linear. This means that temperature or precipitation affects the net revenue positively up to a certain level, above which it causes damage to the crops. The effect of the hydrologic variable on net revenue is also non-linear. The precipitation and the runoff are significant in the model with zone dummy variables. The temperature is not very significant in this model. This means that water is the main factor that explains the spatial variation of revenue in Burkina Faso.

The effects of the soils are negative for all the models, which can be explained by the low fertility level and low water retention capacity of the soils in Burkina Faso. However the introduction of the soil variables made it possible to improve the quality of the regressions.

Agriculture in Burkina Faso is extensive. To compensate for low productivity, farmers increase the area under crops. Although this strategy helps increase the total quantity of produce harvested, it is not efficient because it decreases the yield generally. Most of the time farmers do not have the capacity to manage large areas. This explains why the farmland has a negative effect on revenue.

The household size affects revenue positively. Because the agriculture is extensive, the size of household is important to supply sufficient labor.

As expected, extension service helps improve net revenue.

Irrigation has a positive effect on revenue. As a way of adapting to climate change, it is practiced during the dry season and provides farmers with some additional income. During the rainy season it helps to alleviate rainfall hazards and ensure stable production.

Keeping livestock has a negative effect on net revenue. This is surprising, since integrated crop and livestock farming is promoted because manure improves soil productivity and the animals provide the farmer with transport.

Burkina Faso does not use paid labor much in agriculture, so there are very few agricultural employees, and they are paid only for work performed during busy periods in the farming calendar.

5.3 Marginal impact of climate on agricultural revenue and elasticities

The marginal effect of the temperature is calculated on the basis of the average temperature of the sample, which is 26°C in the rainy season and 26.6 °C in the dry season. The marginal effect of the precipitation is calculated on the basis of the average annual precipitation of the sample, which is 717mm in the rainy season and 80mm in the dry season. For rainfed farms, the averages refer to sites which do not practice irrigation. No significant difference is observed between the average temperatures for rainfed and irrigated crops. However, precipitation figures for rainfed farms are slightly higher than for irrigated ones for any season. This difference suggests that irrigation is practiced where it is necessary because of lower rainfall, but we see that its development depends on the hydrological potential of the region. Therefore most of the drier areas which have water resources develop irrigation.

Table 7 presents the marginal effects of temperatures and precipitation calculated on the basis of regression models. The marginal effect of precipitation is significant at the threshold of 1% while the marginal effect of temperature is significant at 10% for the model with adaptation. This model shows that if the average annual precipitation increases by 1mm, agricultural incomes will increase by US$2.70/ha on average for all the farms in the sample. The increase will be US$2.56/ha for rainfed farms. The increase will reach US$3.51/ha for farms which have not adopted certain adaptation strategies. This means that the farmers' current practices mitigate the effect of climatic variability. In integrating the zone variables, the marginal effect increases by US$1/ha.

On the other hand, if the average temperatures increase by 1°C the net agricultural incomes will drop by US$19.90/ha for the model with adaptation. This fall in income is weaker for the model without adaptation (US$11.5/ha) but remains non-significant. It is significant and higher in the model with dummy zone variable (US$27.07/ha). The effects of climate on income are slightly mitigated in strictly rainfed zones. This means that the rainfed farms are less vulnerable to the effects of climatic changes, because they integrate the climatic risks better and take enough precautions to protect their incomes. As the model is based on responses from farmers, we can say that the rainfed farms have already adopted other strategies of adaptation to the climate change.

With regard to the elasticity of the climatic variables, we can say that agricultural incomes are very sensitive to variations in precipitation (including irrigated farms). The marginal effects taking into account the practice of irrigation are all non-significant and do not provide interesting information. Thus we cannot compare the rainfed system with the irrigated system, but we think that the relatively low sensitivity observed at the level of all farms is due to the contribution of the irrigated systems to the average income of the sample.

6. Forecasts of climate impacts on Burkina Faso's agriculture

To estimate the impact of climate change on the agricultural income, we have made simulations based on uniform scenarios and scenarios specific to Burkina Faso.

6.1 Uniform scenarios

The uniform scenarios are based on the projections made by IPCC (2001). According to these projections, the world's average surface temperature should increase by 1.4°C to 5.8°C during the period from 1990 to 2100. These results refer to the whole 35 SRES scenarios (Special Report on Emissions Scenarios) and are founded on a certain number of climatic models. According to projections, on average and on the scale of the globe, water vapor, evaporation and precipitation should increase. However, at a regional level, increases and decreases in precipitation are forecast at the same time. The results of last AOGCM (Atmosphere-Ocean General Circulation Model) simulations based on the SRES indicate that precipitation is likely to increase during the summer as well as during the winter at high latitudes. An increase in winter precipitation is also forecast for the average latitudes of the northern hemisphere, in tropical Africa and the Antarctic and an increase in summer precipitation in south and east Asia. In Australia, central America and southern Africa, a regular reduction in winter precipitation is foreseen. In the Sahel, the trend during the past decade shows a reduction in precipitation, hence the necessity for simulating this reduction. On the basis of this information we have examined the effect of climatic changes for the following scenarios: an increase in the temperatures of 2.5°C and 5°C and a reduction in the average rainfall of 7% and 14%.

The results of simulations are shown in Table 9. As expected, the increase in the temperature and the reduction in precipitation must inevitably involve a reduction in incomes with regard to the marginal effects obtained. What is interesting here is to see the extent to which these variations influence incomes. The simulations show that a rise in temperature of 5°C on average will reduce incomes by 93% for all farms. A fall in the annual average precipitation of 7% will mean a total loss of income for all the farms (ceteris paribus). But adaptation is part of human nature, so these alarming forecasts will certainly be mitigated.

6.2 Specific climate change scenarios for Burkina Faso

This section examines the impact of the climate scenarios specific to Burkina Faso. Strzepek and McCluskey (2006) have developed climate evolution models for the period between 2050 and 2100 within the framework of the hydrology component for the GEF/WB Project. These models are based on the A2 and B2 scenarios of SRES and provide specific forecasts by country. They all forecast a rise in temperatures for Burkina Faso (Table 9). These rises will vary from 2.4°C to 3.9°C in 2050 and from 5.7°C to 9.7°C in 2100 for the A2 scenario. The B2 scenario envisages increases of between 2.4°C and 3.8°C in 2050 and between 4°C and 7.1°C in 2100. This latter scenario looks less alarming.

The models give the same forecasts for precipitation whatever the scenario is (A2 or B2). Four of the five models predict an increase in precipitation from 1% to 12% in 2050 and from 3% to 30% in 2100. Only one model foresees a decrease in precipitation of about 4% in 2050 and 9% in 2100 . These forecasts are presented in Tables 15 and 16. (See Strzepek and McCluskey, 2006.)

We examined a few of these models with varying predictions. Thus we kept the models cs-a2 and cs-b2 which forecast falls in precipitation and large increases in temperature, models ec-a2 and ec-b2 which foresee the highest increases in precipitation, and finally models ha-a2 and ha-b2 which show average forecasts. The details of the selected scenarios are presented in Table 7.

The results of simulations presented in Table 10 show that the models cs-a2 and cs-b2 constitute the most alarming models for Burkina Faso. According to the cs-a2 model, farmers will lose 72% of their income in 2050 and 177% in 2100 following the increase in temperatures. The decrease in precipitation predicted by this model will result in a reduction in farm households' income of from 84% in 2050 to 190% in 2100. The cumulative effect of the two factors will be dramatic for the farmers who will experience the total erosion of their incomes by the 2050s.

With regard to the other models (ec-a2, ec-b2, ha-a2 and ha-b2) the increases in the temperature certainly lead to a reduction in incomes but at the same time the increases in precipitation lead to a rise in incomes. The loss of income is thus compensated for by the profits generated by the increase in rains. For example, according to the ec-a2 model, the farms will lose 61% of their income in 2050, but at the same time the increases in precipitation predicted by this model will increase incomes by 253%. The combined effect will be positive for incomes. If things evolve this way, rainfed agriculture would adapt better than irrigated agriculture in Burkina Faso. Indeed, irrigation is practiced only for specific crops such as rice and for truck farming in small areas in the dry season. If the increase in precipitation relates only to the rainy season (undoubtedly), it will be useful for the irrigated system only through the filling of dams and the re-supplying of ground waters. However. rising temperatures especially during the dry season will increase the crops' demand for water.

7. Farmers' perceptions of and adaptations to climate change

This section analyzes farmers' perceptions of climate change and the adaptations developed and implemented by them. We examined farmer's perceptions of short-term and long-term climate effects and the main finding is that there is no significant difference between the two. We observed that strategies developed to cope with the effects of climate variability (i.e. short-term) and climate change (i.e. long-term effect) are essentially the same.

7.1: Perception of climate change

Climatic variability and changes are phenomena that are perceived by the surveyed households. They noticed some changes in temperatures: 26% noticed an increase and only 1% a decrease. According to the outcome of the survey, 74% of the households asserted that there had been changes in rainfall over the past years. They noticed this change in the form of (i) a diminution in quantity of rain and/or in the number of rainy days (35.5%), (ii) irregularity rains (14%), (iii) a late start to the rains (10.8%), and (iv) an early and abrupt end to the rains (12.6%). The decline in rains was perceived more in the Sudano-Sahelian and Sahelian zones than in the Sudanese zone where rains are abundant. (See Table 11).

7.2. Adaptation to climate changes

Farmers strategies for adapting to climate changes included:

- Water and soil management and agro-forestry techniques, such as the building of lines of stones, dikes, quickset hedges, windbreaks, zai, half-moons, etc.[6]

- Improved variety, mainly the use of early, high yield and adapted varieties of crops.

- Good application of cropping techniques. This means better application of technology and following the advice provided by the extension service about such matters as plowing before sowing, keeping to sowing dates, applying fertilizer, early sowing, flat plowing and sowing, and rotating crops.

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[6] Zai is a technique consisting of digging small holes during the dry season in the barren soil, putting a handful of manure in each hole and waiting for the first rainfall to sow crops in them. This makes the soil productive. Half-moon is a technique for harvesting rainwater. Farmers build a half moon-shaped structure oriented to the upstream to capture the runoff. This is particularly good for agroforestry.

- Fertilizer application, composting, mulching, and placing animals in the fields.
- Reforestation, done communally or individually.
- Space occupation, consisting of using lowlands, extending the cultivated areas, changing the production site and the fields, practicing transhumance as far as animal husbandry is concerned, etc.
- Diversification of crops and activities, for example by short cycle cultivation, operating small businesses, practicing truck farming, and keeping livestock.
- Protecting the environment and natural resources, for example fighting bush fires, stopping animals wandering and preventing excessive wood cutting.
- Equipment/mechanization of the farm. particularly the use of animal traction,
- Faith, in the form of farmers' sacrifices and prayers for rain. This is the normal practice when there are pockets of drought during the rainy season.
- Migration, which is the final way of adapting to climate change if farmers are just unable to cope.

Tables 12 and 13 show the adaptations to temperature and precipitation change implemented in Burkina Faso by agro-climatic zones.

8. Conclusions and implications for policy

This study explores the impact of climate change on agriculture in Burkina Faso. It uses primary household level data together with secondary climate, hydrological and soil data to implement the Ricardian cross-sectional approach. The primary data comes from a large survey of 1530 households in 51 districts across the country (but about 1000 households were used for the Ricardian model). The study uses the Ricardian approach to measure the relationship between the net crop revenue and climate variables (temperature and precipitation), soil variables, relevant hydrology variables (runoff) and socio-economic variables (farmland, household size, animal power, livestock, irrigation and hired labor). It tests three models (without adaptation, with adaptation, and with zone dummy variable) and two farming systems (dryland farms and all farms including irrigated ones). It also explores the farmer's perceptions and adaptation strategies to climate change. It determines how Burkina Faso farms would respond to the IPCC (2001) and SRES climate change scenarios.

The results of the study show that climate affects crop net revenue in Burkina Faso. The marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue falls by US$19.9/ha. On the other hand, if the precipitation increases by 1 mm, the net revenue increases by US$2.7/ha.

The elasticity shows that agriculture in Burkina Faso is more sensitive to precipitation changes than to temperature changes. The elasticity is 14.7 for the precipitation and 3.6 for the temperature. Dryland farms are more sensitive to precipitation and less sensitive to temperature than all farms including irrigated ones.

The analysis of the climate change scenarios shows that scenarios of decreasing precipitation with rising temperatures will cause more damage to agriculture in Burkina Faso. On the other hand the scenarios of increasing precipitation and rising temperature will be tolerable because the positive impact of precipitation will compensate for the negative effect of the warming. As the climate in Burkina Faso is already hot and dry, the scenarios of decreasing precipitation and rising temperature will be very harmful for crop production.

According to the model cs-a2 (specific to Burkina Faso), all farms will lose 72% of their net revenue due to the increase in temperature and 84% due to the decrease in precipitation in 2050. The cumulative effect of these temperature and precipitation changes will be dramatic for the farms, which could lose all their net revenue in 2050. On the other hand, according to the model ec-a2, the farms will lose 61% of their revenue by 2050, but the increases in precipitation foreseen by this model will entail a gain of revenue of 253%, so the combined effect will be positive for farms.

The study reveals that some variables used in the regression are significant and have a positive effect on net revenue. For example, extension and irrigation are significant and have a positive effect and can be applied as adaptation options.

The analysis of farmers' perceptions indicates that farmers in the surveyed households have observed short- and long-term changes in the climate. They found that some changes have occurred in the temperatures, with 26% noticing them as an increase.

Facing the climatic variations and climate change, the surveyed farmers developed strategies for adapting, including water and soil management, agro-forestry techniques, crop management techniques, use of improved varieties, use of organic fertilizer (compost, mulching and placing animals in the fields); planting trees, extending land, diversification of crops and activities, etc.

The results of the study confirm the importance of climate for revenue and the need to take steps to reinforce existing adaptation options and develop new ones. This has political implications: constraints on adaptation should be removed and better knowledge of climate change promoted. The major actions to be undertaken are (i) promoting ways of adapting to climate change, (ii) developing new ways of adapting, and (iii) creating a unit for research into climate, development and societies.

(i) Promoting ways of adapting to climate change

The adoption of adaptation measures encounters financial constraints (poverty of the producers, lack of credit), material constraints (lack of equipment and working material, lack of input for the application of adaptation measures, etc.) and lack of knowledge (no mastery of the adaptation techniques, lack of information about adaptation techniques, etc.). To remedy this situation, the State must ensure:

- an improvement of the agricultural households' financial self-promotion capacity through the promotion of revenue generating activities;
- financing of the rural area by setting up suitable financial systems that will allow small producers to have access to credit; and

- large scale dissemination of adaptation technologies by boosting supervision and extension.

(ii) Developing new ways of adapting

The State must favor the participative development of technologies adapted to the agro-ecological and socio-economic conditions. The strategies developed and mostly used in the Sahelian zone should be tested in the Sudanese zone in order to adapt them to this environment which is more affected by climatic worsening. In addition, it must reinforce the link between research and development for a better transfer of adaptation measures to farmers.

(iii) Creating a unit for research into climate, development and societies

Indeed, the climatic changes are new concerns and for this reason national research practically does not have available results to face them. Therefore research programs should be developed on the phenomenon and activities carried out in the framework of a specialized unit in order to provide as much information as possible.

The study considers technology to be a constant and in predicting impacts of climate change does not take into account farmers' ongoing adaptations. Not all adaptation options revealed by the analysis of farmer's perceptions and adaptations have been taken into account in this study. The study looked at crops overall and did not examine the impact crop by crop. Future studies should take an interest in the mono crop model. This would permit researchers to target those crops most important for the country, for example the cotton that brings in more than 50% of Burkina Faso's returns of exports. This study constitutes a first step in assessing the economic impact of climate changes in the country. It will serve as reference for other research on climate change impact in Burkina Faso.

REFERENCES

Bazzaz F & Sombroek W, 1997. Changements du climat et production agricole: Effets directs et indirects du changement des processus hydrologiques, pédologiques et physiologiques des végétaux. Polytechnica/FAO (Food and Agriculture Organization).

BUNASOLS (Bureau National des Sols), 1985. Etat de connaissance de la fertilité des sols du Burkina Faso. Document technique No. 1, Ouagadougou, Burkina Faso.

Dembele Y & Some L, 1991. Propriétés hydrodynamiques des principaux types de sol du Burkina Faso. In *Soil water balance in the Sudano-Sahelian zone*, proceedings of Niamey workshop, February 1991. IAMS Publication No. 199, 217-227 Institut National de la Statistique et de la Démographie (INSD) 1996: Leprofil de pauvreté au Burkina Faso 1ère edition. Ministère de l'Economie et du Plan, Ouagadougou, Burkina Faso.

FAO (Food and Agriculture Organization), 2003. The digital soil map of the world: Version 3.6 (January), Rome, Italy.

Guinko S, 1984. *Végétation de la Haute-Volta*. Thèse de Doctorat d'Etat, Université de Bordeaux III.

INSD (Institut National de la Statistique et de la Demographie), 2000. Ministère de l'Économie et des Finances, Burkina Faso, Annuaire statistique du Burkina Faso 1999, Ouagadougou, Décembre.

INSD (Institut National de la Statistique et de la Demographie), 2006. Ministère de l'Economie et du Développement, Burkina Faso, Données statistiques, statistiques structurelles. http://www.insd.bf/ Created 17 February 2006. Accessed 28 February 2006.

IPCC (Intergovernmental Panel on Climate Change), 2001, *Climate Change 2001: The Scientific Basis*. New York: Cambridge University Press.

Kumar, K and Parikh, J, 2001, Indian agriculture and climate sensitivity. *Global Environmental Change* 11: 147-152.

Kurukulasuriya P & Mendelsohn R 2006. A Ricardian analysis of the impact of climate change on African cropland. CEEPA Discussion Paper No. 8, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Mendelsohn R & Dinar A, 2003. Climate, water, and agriculture. *Land Economics* 79(3): 328–341.

Mendelsohn R, Nordhaus W & Shaw D, 1994. The impact of global warming on agriculture: A Ricardian analysis. *American Economic Review* 84: 753–771.

Ouedraogo M, 1999. Contribution à l'évaluation de l'Impact Economique des Changements Climatiques sur l'Agriculture Marocaine», Mémoire de 3ème cycle Agronomie/

spécialisation Agro-économie, Royaume du Maroc, Institut Agronomique et Vétérinaire Hassan II Rabat-Instituts, Maroc, Septembre, 1999.

Rao DG & Sinha SK, 1994. Impact of climate change on simulated wheat production in India. In Rosenzweig C and Iglesias A (eds), 1994. *Implications of climate change for international agriculture: Crop modeling study.* (EPA 230-B-94-003). US Environmental Protection Agency, Washington DC.

Reilly J, Hohmann N & Kane S, 1994. Climate change and agricultural trade: Who benefits, who loses? *Global Environmental Change* 4(1): 24–36.

Rosenzweig C & Iglesias A (eds), 1994. *Implications of climate change for international agriculture: Crop modeling study.* (EPA 230-B-94-003). US Environmental Protection Agency, Washington DC.

Rosenzweig C & Parry M, 1994. Potential impact of climate change on world food supply. *Nature* 367: 133–138.

Sanghi A, Mendelsohn R & Dinar A, 1998. The climate sensitivity of Indian agriculture. In Dinar A et al. (eds), 1998. Measuring the impact of climate change on Indian agriculture. World Bank Technical Paper 402. World Bank, Washington, DC.

Some L & Sivakumar MVK, 1994. Analyse de la longueur de la saison culturale en fonction de la date du début des pluies au Burkina Faso. Compte rendu des Travaux No.1 INERA Burkina Faso ICRISAT Niger.

Strzepek K & McCluskey A, 2006. District level hydroclimatic time series and scenario analyses to assess the impacts of climate change on regional water resources and agriculture in Africa. CEEPA Discussion Paper No. 13, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

UEMOA (Union Economique et Monétaire Ouest Africaine) http://www.banque-france.fr/fr/eurosys/telechar/zonefr/uemoa/burkina_faso.pdf Accessed 23 February 2006.

World Bank, 2003. Africa rainfall and temperature evaluation system (ARTES). World Bank, Washington DC.

Table 1: Distribution of agricultural household and farm typology in Burkina Faso

Criteria	Typologies	No. of households	% of farms
Inputs + equipment	Without fertilizer, without equipment	539 336	60.96
	With fertilizer, without equipment	85 580	9.67
	Without fertilizer, with equipment	172 288	19.47
	With fertilizer, with equipment	87 481	9.89
Surface	Small farms (<3ha)	441 577	49.91
	Average size farms (3 à 5ha)	209 560	23.69
	Large farms (>5ha)	233 551	26.39
Population	Small size (<5 persons)	253 689	28.67
	Average size (5 to 9 persons.	295 631	33.41
	Big size (>10 persons).	335 369	37.90

Table 2: Distribution of the samples per agricultural region

Agricultural regions	Districts	No. of sites	No. of producers
Centre	Toece, Mogtedo, Bousse, Zitenga	4	120
Centre-East	Zabre, Comin-Yanga, Pouytenga	3	90
Centre-North	Tikare, Tougouri, Barsalogho	3	90
Centre-West	Sabou, Didyr, Boura, To	4	120
Centre-South	Tiebele, Sapouy, Gomboussougou	3	90
East	Bogande, Diapangou, Matiacoali, Bartiebougou, Pama, Botou, Tansarga	7	210
Mouhoun	Poura, Sanaba, Bomborokui, Safane, Kougny, Kassoum	6	180
North	Titao, Kirsi, Thiou, Gourcy	4	120
Sahel	Oursi, Dori, Tongomayel, Diguel, Sebba	5	150
Cascades	Mangodara, Sideradougou, Oueleni	3	90
Hauts-Bassins	Bama, Toussiana, Djigouera, N'dorola, Koumbia	5	150
South-West	Tiankoura, Koper, Kpuere, Loropeni	4	120
Total		**51**	**1530**

Table 3: Descriptive statistics of variables used in regression

Variable	Number of obs	Mean	Std dev	Min	Max
Dependent variable					
Net revenue	861	145.6	210.81	-743.58	1666.14
Climatic variables					
Rainy season temperature	999	26.6	2.37	23.24	32.55
Rainy season temperature squared	999	713.2	129.98	539.94	1059.70
Dry season temperature	999	26.0	1.36	24.06	29.22
Dry season temperature squared	999	679.7	71.94	578.97	853.74
Rainy season precipitation	999	716.6	122.87	393.86	891.59
Rainy season precipitation squared	999	528659.1	169161.50	155128.30	794926.80
Dry season precipitation	999	79.7	34.23	17.30	155.83
Dry season precipitation squared	999	7530.1	5949.05	299.17	24281.95
Hydrology variable					
Mean runoff	999	16.7	8.08	1.51	33.72
Mean runoff squared	999	345.6	290.78	2.27	1136.99
Household farm variables					
Farmland	999	6.944	4.846	0.5	42
Household size	997	10.738	6.215	1	41
Log (household size)	997	2.219	0.567	0	3.71
Livestock (1/0)	999	0.969	0.173	0	1
Extension (1/0)	982	0.842	0.365	0	1
Irrigation (1/0)	999	0.056	0.230	0	1
Hired labor use (1/0)	999	0.357	0.479	0	1
Animal power (1/0)	999	0.646	0.479	0	1
Soil variables					
Soil 1: Luvic arenosols (Ql)	999	0.043	0.175	0	1
Soil 2: Eutric gleysols (Re)	999	0.270	0.362	0	1.1
Soil 3: Solodic planosols (Ws)	999	0.042	0.113	0	0.5
Soil 4: Gleyic luvisols (Lg)	999	0.193	0.308	0	1
Soil 5: Ferric luvisols (Lf)	999	0.115	0.228	0	1
Soil 6: Phinthic luvisols (Lp)	999	0.167	0.309	0	1
Soil 7: Vertic cambisols (Bv)	999	0.054	0.143	0	0.8
Soil 8: Chromic cambisols (Vc)	999	0.028	0.111	0	0.7
Soil 9: Eutric cambisols (Be)	999	0.014	0.078	0	0.5
Soil 10: Dystric nitosols (Nd)	999	0.032	0.118	0	0.5
Soil 11: Lithosols (I)	999	0.024	0.076	0	0.5

Table 4: Regression results of model without adaptation (all farms)

Variable	Coefficient		t
Rainy season temperature	-426.9	***	-2.66
Rainy season temperature squared	7.907	***	2.62
Dry season temperature	722.8	*	1.71
Dry season temperature squared	-13.98	*	-1.72
Rainy season precipitation	-2.415	*	-1.76
Rainy season precipitation squared	0.001		1.11
Dry season precipitation	15.12	***	4.32
Dry season precipitation squared	-0.066	***	-4.62
Mean runoff	-15.72	**	-2.25
Mean runoff squared	0.632	***	3.38
Soil 1: Luvic arenosols (Ql)	-192.1		-0.94
Soil 2: Eutric gleysols (Re)	-144.7		-0.75
Soil 3: Solodic planosols (Ws)	-520.0	**	-2.34
Soil 4: Gleyic luvisols (Lg)	-183.5		-0.96
Soil 5: Ferric luvisols (Lf)	-322.7	*	-1.7
Soil 6: Phinthic luvisols (Lp)	-357.3	*	-1.72
Soil 7: Vertic cambisols (Bv)	-418.1	**	-2.04
Soil 8: Chromic cambisols (Vc)	-284.8		-1.5
Soil 9: Eutric cambisols (Be)	-735.8	***	-3.38
Soil 10: Dystric nitosols (Nd)	-945.2	***	-3.63
Soil 11: Lithosols (I)	-289.9		-0.99
Constant	-2625		-0.55
Number of observations	861		
F	9.34		
R-squared	0.1542		

* Significant at 10% level ** Significant at 5% level *** Significant at 1% level

Table 5: Regression results of model with adaptation (all farms and dryland farms)

Variables	All farms			Dryland farms		
	Coefficients		T	Coefficients		T
Rainy season temperature	-522.6	***	-2.62	-605.5	***	-3.04
Rainy season temperature squared	9.910	***	2.64	11.61	***	3.1
Dry season temperature	892.4	**	2.08	1125	***	2.75
Dry season temperature squared	-17.61	**	-2.12	-22.12	***	-2.8
Rainy season precipitation	-1.465		-0.82	-2.43		-1.42
Rainy season precipitation squared	0.001		0.52	0.001		1.29
Dry season precipitation	12.30	***	3.52	12.58	***	3.67
Dry season precipitation squared	-0.056	***	-3.89	-0.060	***	-4.14
Mean runoff	-12.19	*	-1.94	-1.553		-0.33
Mean runoff squared	0.536	***	3.18	0.273	*	1.89
Soil 1: Luvic arenosols (Ql)	-133.3		-0.66	-18.19		-0.11
Soil 2: Eutric gleysols (Re)	-133.8		-0.71	-29.87		-0.19
Soil 3: Solodic planosols (Ws)	-477.4	**	-2.3	-314.9	*	-1.77
Soil 4: Gleyic luvisols (Lg)	-183.5		-0.97	-95.12		-0.6
Soil 5: Ferric luvisols (Lf)	-311.6	*	-1.66	-226.8		-1.42
Soil 6: Phinthic luvisols (Lp)	-318.4		-1.58	-219.5		-1.27
Soil 7: Vertic cambisols (Bv)	-406.4	*	-2.03	-312.7	*	-1.89
Soil 8: Chromic cambisols (Vc)	-264.0		-1.41	-209.3		-1.26
Soil 9: Eutric cambisols (Be)	-628.9	***	-3	-544.1	***	-2.84
Soil 10: Dystric nitosols (Nd)	-896.1	***	-3.52	-765.7	***	-3.14
Soil 11: Lithosols (I)	-276.0		-0.98	-126.1		-0.48
Farmland	-3.429	*	-1.83	-3.266	*	-1.68
Log (household size)	-3.447		-0.19	6.704		0.36
Livestock (1/0)	-50.44		-1.2	-53.25		-1.27
Extension (1/0)	6.182		0.26	14.32		0.58
Irrigation (1/0)	150.8	***	3.63			
Hired labor use (1/0)	-33.6	**	-2.01	-23.49		-1.41
Animal power (1/0)	-28.3		-1.58	-31.24	*	-1.73
Constant	-3739		-0.82	-5690		-1.30
N	843			787		
F	7.25			6.88		
R	0.1942			0.1687		

* Significant at 10% level ** Significant at 5% level *** Significant at 1% level

Table 6: Regression results of model with adaptation and zone dummy variables (all farms and dryland farms)

Variables	All farms			Dryland farms		
	Coefficients		t	Coefficients		t
Rainy season temperature	-390	*	-1.71	-495.7	**	-2.18
Rainy season temperature squared	7.408	*	1.72	9.531	**	2.22
Dry season temperature	219.4		0.37	541.8		0.93
Dry season temperature squared	-4.822		-0.42	-11.02		-0.98
Rainy season precipitation	-6.023	**	-2.1	-6.216	**	-2.23
Rainy season precipitation squared	0.004	**	2.1	0.004	**	2.31
Dry season precipitation	13.26	***	3.49	13.43	***	3.58
Dry season precipitation squared	-0.056	***	-3.58	-0.060	***	-3.82
Mean runoff	-12.98	**	-2.06	-1.998		-0.42
Mean runoff squared	0.546	***	3.25	0.278	*	1.9
Soil 1: Luvic arenosols (Ql)	-26.52		-0.13	65.40		0.37
Soil 2: Eutric gleysols (Re)	-36.16		-0.19	46.06		0.28
Soil 3: Solodic planosols (Ws)	-380.2	*	-1.84	-236.6		-1.34
Soil 4: Gleyic luvisols (Lg)	-40.59		-0.21	16.72		0.1
Soil 5: Ferric luvisols (Lf)	-218.1		-1.11	-153.3		-0.91
Soil 6: Phinthic luvisols (Lp)	-228.4		-1.11	-150.3		-0.85
Soil 7: Vertic cambisols (Bv)	-333.7	*	-1.65	-257.6		-1.53
Soil 8: Chromic cambisols (Vc)	-153.1		-0.79	-122.7		-0.7
Soil 9: Eutric cambisols (Be)	-406.0	*	-1.78	-366.9	*	-1.76
Soil 10: Dystric nitosols (Nd)	-798.4	***	-3.04	-692.0	***	-2.75
Soil 11: Lithosols (I)	-147.7		-0.51	-27.25		-0.1
Farmland	-3.326	*	-1.78	-3.152		-1.63
log (household size)	-1.156		-0.06	8.416		0.45
Livestock (1/0)	-46.77		-1.1	-50.62		-1.19
Extension (1/0)	11.38		0.47	19.16		0.75
Irrigation (1/0)	156.3	**	3.76			
Hired labor use (1/0)	-36.13	**	-2.16	-25.91		-1.56
Animal power (1/0)	-30.96	*	-1.71	-33.52	*	-1.85
South Sudanese zone (1/0)	-48.11		-0.44	-29.05		-0.27
North Sudanese zone (1/0)	124.3		1.17	110.5		1.04
Constant	4613		0.71	1582		0.25
N	843			787		
F	7.42			6.94		
R	0.1994			0.1729		

* Significant at 10% level ** Significant at 5% level *** Significant at 1% level

Table 7: Marginal impact of climate on net revenue (US$/ha) in Burkina Faso
(Evaluated at mean of all farms and dryland farms from coefficients in Tables 4, 5 and 6)

	Without adaptation				Model with adaptation				Model with zone dummy			
	All farms		**Dryland**		**All farms**		**Dryland**		**All farms**		**Dryland**	
Temperature	-11,5		-12,2		-19,9	*	-15,62		-27,07	**	-21,51	*
	(-2,08)		(-2,39)		(-3,60)		(-3,07)		(-4,89)		(-4,23)	
Precipitation	3,51	***	3,43	***	2,7	***	2,56	***	3,86	***	3,52	***
	(19,21)		(20,39)		(14,75)		(15,23)		(21,12)		(20,92)	

* Significant at 10% level ** Significant at 5% level *** Significant at 1% level
() number in bracket represents the elasticity of climate variable.

Table 8: Impacts from Uniform Climate Scenarios on net crop revenue in Burkina Faso
(all farms and dryland farms) from coefficients in Table 5

Scenarios	All farms		Dryland farms	
	ΔNet revenue (US$/ha)	**ΔNet revenue (%)**	**ΔNet revenue (US$/ha)**	**ΔNet revenue (%)**
Temperature warming (2.5°C)	-68	-46%	-54	-40%
Temperature warming (5°C)	-135	-93%	-108	-80%
Precipitation decreasing (7%)	-215	-148%	-196	-146%
Precipitation decreasing (14%)	-431	-296%	-392	-293%

Table 9: Specific scenarios for Burkina Faso

	Year	Temperature (°C)	Precipitation (in %)		
		A2 Scenarios			
cs-a2	2050	3.9	cs-a2	2050	96%
	2100	9.5		2100	91%
ec-a2	2050	3.3	ec-a2	2050	112%
	2100	8.3		2100	130%
ha-a2	2050	3.9	ha-a2	2050	106%
	2100	9.7		2100	115%
		B2 Scenarios			
cs-b2	2050	4.0			
	2100	7.1			
ec-b2	2050	3.3			
	2100	5.8			
ha-b2	2050	3.8			
	2100	6.7			

Source: Strzepek & McCluskey, 2006

Table 10: Impacts of specific scenarios on net revenue in Burkina Faso (all farms and dryland farms) from coefficients in Table 5

Models	Year	Temperature effect				Precipitation effect			
		All farms		Dryland		All farms		Dryland farms	
		ΔNR (US$/ha)	ΔNR (%)	ΔNR (US$/ha)	ΔNR (%)	ΔNR (US$/ha)	ΔNR (%)	ΔNR (US$/ha)	ΔNR (%)
A2- Scenarios									
cs-a2	2050	-106	-72%	-84	-63%	-123	-84%	-112	-84%
	2100	-257	-177%	-204	-153%	-277	-190%	-252	-188%
ec-a2	2050	-89	-61%	-71	-53%	369	253%	336	251%
	2100	-225	-154%	-179	-133%	923	634%	840	628%
ha-a2	2050	-106	-72%	-84	-63%	185	127%	168	126%
	2100	-263	-180%	-209	-156%	461	317%	420	314%
B-2 – Scenarios									
cs-b2	2050	-108	-74%	-86	-64%	-123	-84%	-112	-84%
	2100	-192	-132%	-153	-114%	-277	-190%	-252	-188%
ec-b2	2050	-89	-61%	-71	-53%	369	253%	336	251%
	2100	-157	-108%	-125	-93%	923	634%	840	628%
ha-b2	2050	-103	-71%	-82	-61%	185	127%	168	126%
	2100	-181	-125%	-144	-108%	461	317%	420	314%

Table 11: Perception of change in rains by agro-climatic zone in Burkina Faso (% of farmers)

Changes in precipitation	Sahelian	Sudano-Sahelian	Sudanese	Country
Decline of rains	32.9	42.9	23.8	35.5
Irregularity of rains	0.9	18.2	17.4	14.0
Early and sudden stopping of rains	6.7	14.3	14.4	12.6
Late beginning of rains	10.1	8.3	16.2	10.8
Pocket of drought	4.3	5.0	18.5	8.5
Diminution of rainy season duration	4.6	10.0	5.1	7.4
Strong rains	0.3	3.5	7.7	3.9
Inundation	-	3.8	5.9	3.5
Strong winds	0.3	1.3	0.8	0.9
Others	2.1	0.1	0.8	0.8
Total	**85.7**	**71.4**	**69.2**	**74.1**

Total number of farmers: 1510

Table 12: Adaptations to the changes in temperature in Burkina Faso (% of farmers)

Adaptations to the changes in temperature	Sahelian	Sudano-Sahelian	Sudanese	Country
Organic fertilizer amendment	24.1	16.8	19.2	19.1
Water and soils management, agro-forestry techniques	37.2	8.3	21.3	18.4
Reforestation	23.8	16.9	15.9	18.2
Good application of cropping techniques	3.7	5.3	5.6	5.0
Environment and natural resources protection	7.0	1.3	2.3	2.9
Improved variety	2.1	1.8	5.6	2.9
Equipment/mechanization of the farm	0.9	3.9		2.2
Space occupation	2.1	0.7	0.8	1.0
Diversification		0.6	0.5	0.4
Faith			0.3	0.1
Others	0.3	0.1		0.1
Total	**31.1**	**14.0**	**21.8**	**20.0**

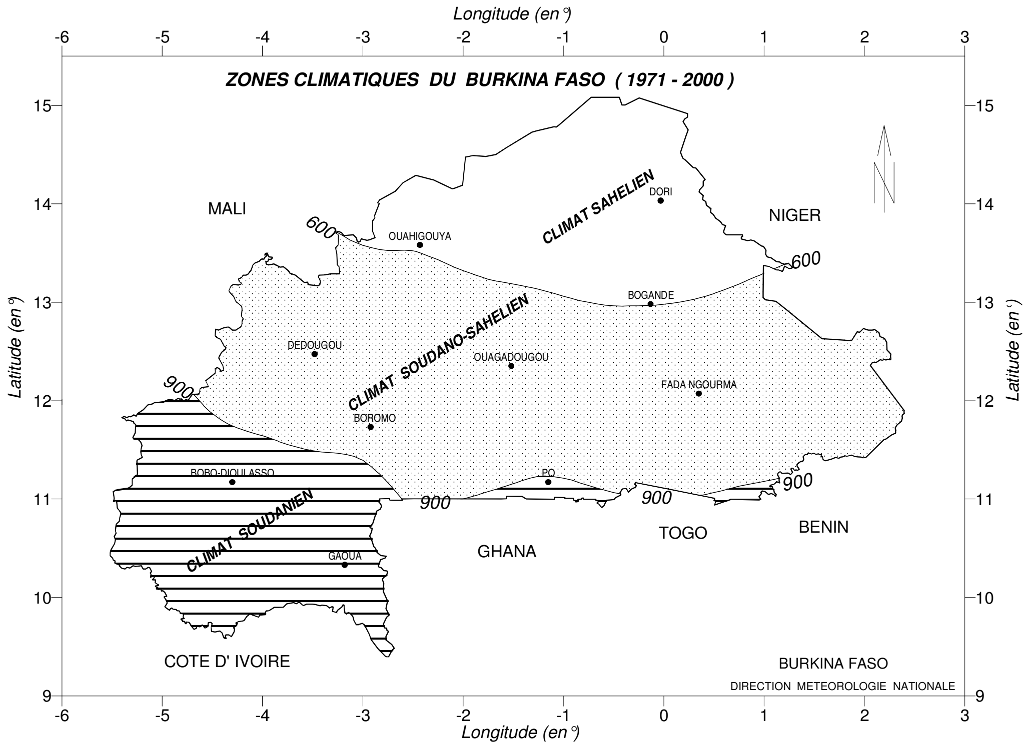
Total number of farmers: 1510

Table 13: Adaptations to the changes in precipitation in Burkina Faso (% of farmers)

Adaptations to the changes in precipitation	Sahelian	Sudan- Sahelian	Sudanese	Country
Improved variety	38.4	36.3	18.7	32.0
Water & soils management, agro-forestry techniques	34.1	31.1	14.9	27.4
Good application of cropping techniques	33.5	19.2	19.7	22.6
Organic fertilizer use	31.1	23.6	10.3	21.7
Space occupation	4.0	10.1	8.7	8.3
Reforestation	9.1	3.3	11.0	6.7
Diversification of crops and activities		6.3	6.2	4.8
Equipment / mechanization of the farm	0.3	5.0		2.6
Faith	0.6	1.1	1.5	1.1
Environment and natural resources protection	2.7	0.4		0.8
Others	0.3	1.0		0.6
Total	**90.9**	**70.4**	**60.3**	**72.3**

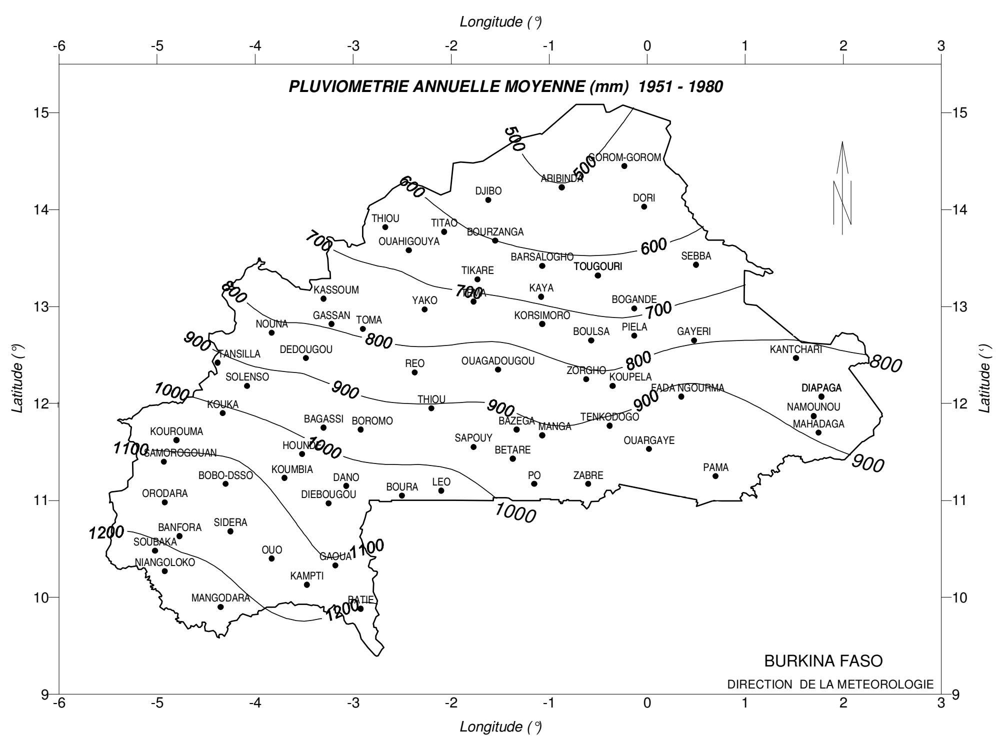
Total number of farmers: 1510

Figure 1: Agro-climatic zones in Burkina Faso



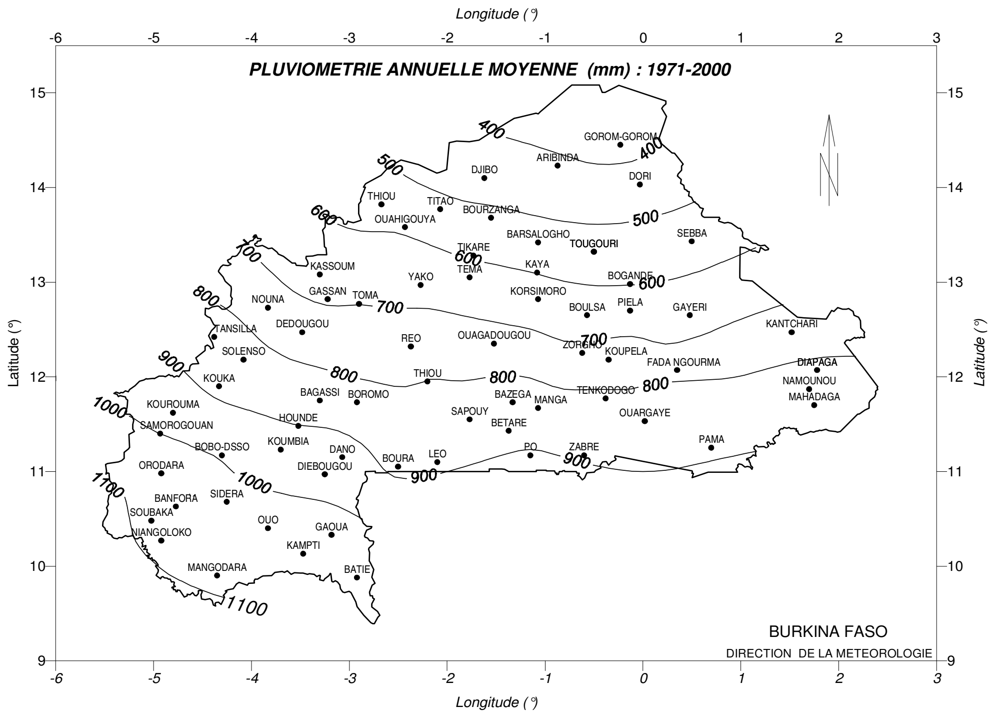
Source: National meteorological service of Burkina Faso

Figure 2: Annual average rainfall (mm) from 1951 to 1980



Source: National meteorological service of Burkina Faso

Figure 3 Annual average rainfall (mm) from 1971 to 2000



Source: National Meteorological Services of Burkina Faso

Figure 4: Distribution of crops per agro-climatic zone

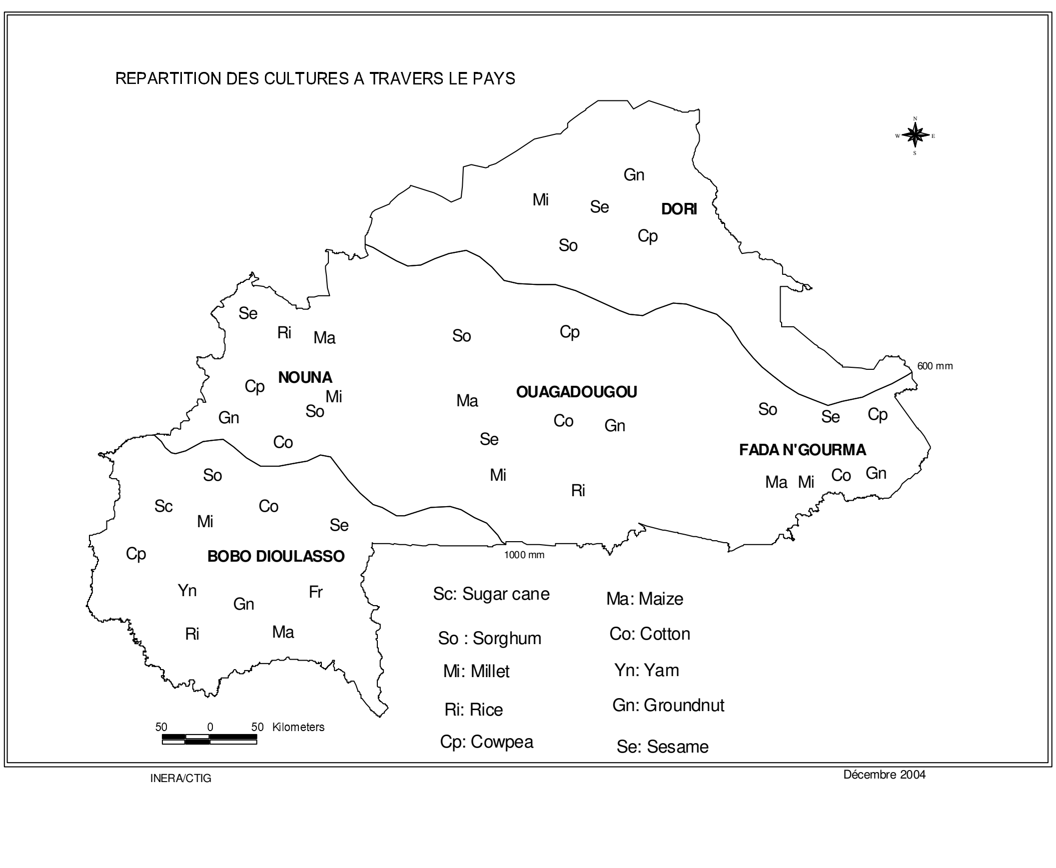
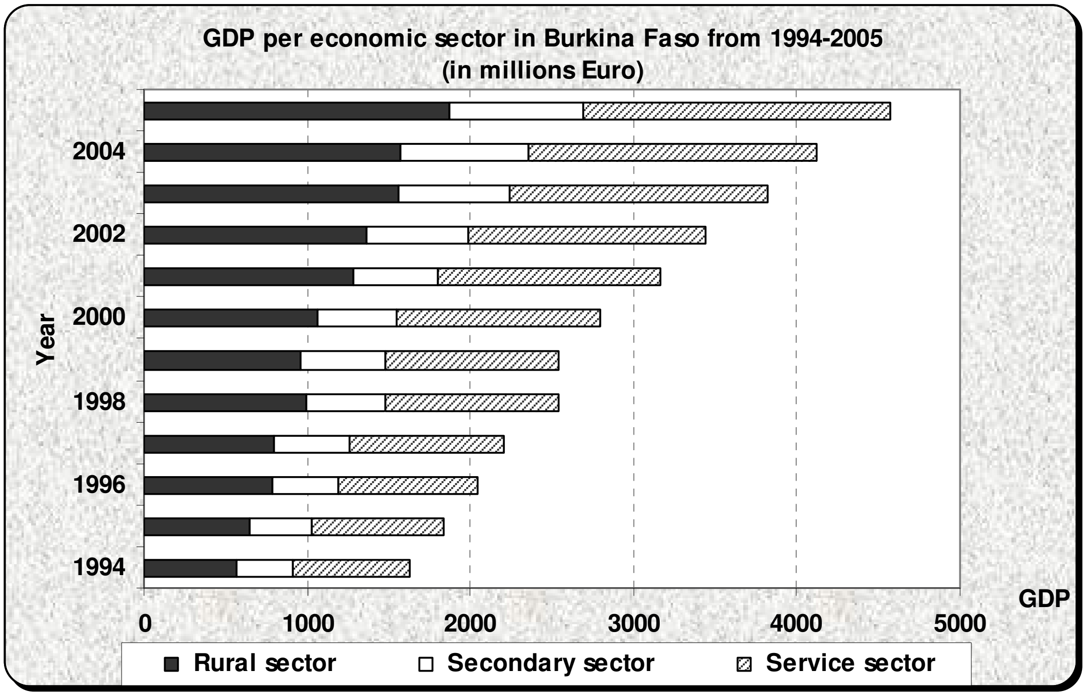


Figure 5: Evolution of GDP per economic sector in Burkina Faso from 1994 to 2005 (in millions Euros)



Source of data : INSD 2006 and UEMOA (Union Economique et Monétaire Ouest Africaine) 2006

Figure 6: Identification of districts for surveys

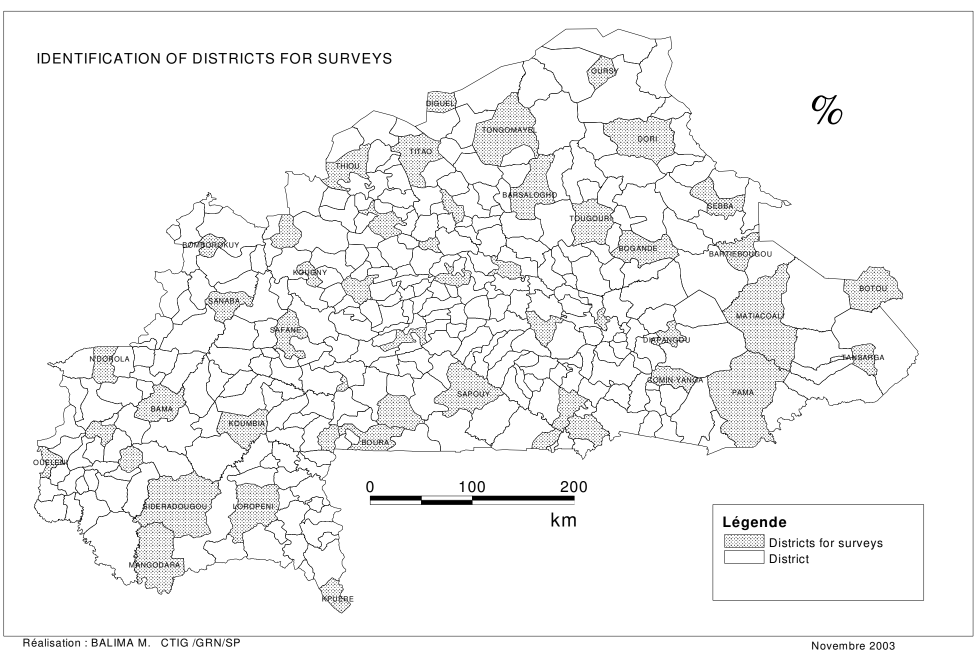
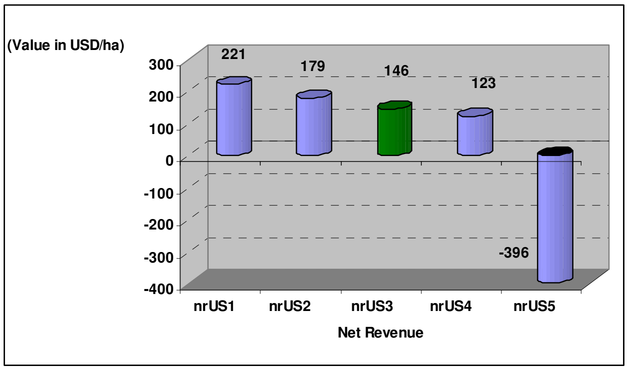


Figure 7: Sample mean net revenue per ha in Burkina Faso



(i) nrUS1 = Gross revenue –Total variable costs for cropping activities (storage, losses and food cost)

(ii) nrUS2 = nrUS1 – Cost of fertilizers and pesticides

(iii) nrUS3 = nrUS2 – Cost of light and heavy machinery and animal power

(iv) nrUS4 = nrUS3 – Cost of hired labor for crop activities

(v) nrUS5 = nrUS4 – Cost of household labor for crop activities

Figure 8: Sample mean net revenue per agro-climatic zone of Burkina Faso (in US$/ha)

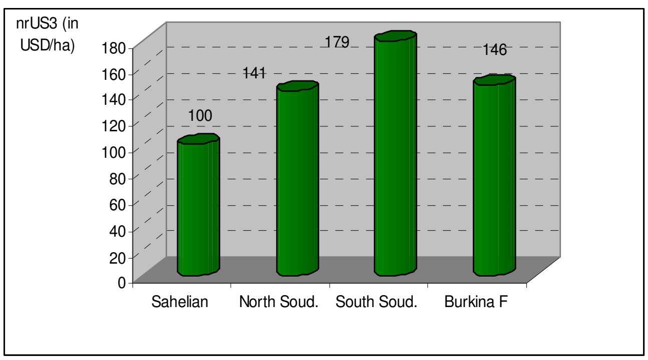


Figure 9: Sample mean net revenue : all farms, dryland and irrigated farms in BF (in US$/ha)