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Changements climatiques et Intensification Durable au Sénégal: Une Etude de Cas du Système de production Biologique des Légumes dans la Zone des Niayes

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Declaration

I declare that this thesis, which is submitted for the degree of PhD in Economics (specifically in Climate Change Economics) at the Cheikh Anta Diop University of Dakar, is entirely my own work and has not been submitted anywhere else.

Part of this thesis have been presented in conferences and submitted for publication in journals.

Any error in thinking and omissions are entirely my own responsibility.

Dedication

To the two Heroes of my life, my father Mamadou Assimiou BA and my mother Mariama Ciré Cissokho who are my source of hope and inspiration. This work is also dedicated to my husband Mamadou Malick Bah and my daughter Salimatou Bah who supported my absence throughout the completion of this PhD degree.

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Acronyms and Abbreviations

ADF	African Development Fund
CA	Conservation Agriculture
CSA	Climate Smart Agriculture
DFID	UKs Department of Foreign and International Development
ENDA-TM (Pronat)	Environment and Development Third World for Nature Protection
FAO	Food and Agriculture Organization
FCFA	Franc Communanté Finacière Africaine
GAP	Good Agricultural Practices
GEF	Global Environment Facility
GHGs	Greenhouse Gas Emissions
IFOAM	International Federation of Organic Agriculture Movements
IPCC	Intergovernmental Panel on Climate Change
ISRA	Senegalese Institute for Agricultural Research
JICA	Japanese International Cooperation Agency
NAPA	National Adaptation Program of Action
OECD	Organization for Economic Co-operation and Development
TROPICASEM	Private Research Company specialized in the production and distribution of vegetable seeds.
UNDP	United Nations Development Program
UNEP	United Nations Environment Program

UNFCCC	United Nations Framework Conventions on Climate Change
UNITAR	United Nation Institute for Training and Research

ABSTRACT

This study aims to investigate the present production and marketing systems of vegetables production in the Niayes so as to analyze the potential of organic farming to enhance framers' productivity and to mitigate climate change.

A farm model is used to study the economic and environmental performances of the organic vegetable farming system compared to the conventional vegetable farming system in the rural community of Diender. The analysis is undertaken in two representative farms (conventional and organic). Gross margin is regarded as economic indicator while carbon emissions equivalent are regarded as environmental indicators. Moreover, risk analysis in the two farming systems are performed based on the Expected value- variance (E- V) model. This is carried out through performing Excel based and mathematical programming analyses, using data that describe a typical organic vegetable farm and a conventional vegetable farm in the Niayes. Results about the analysis of the performance of the market through marketing margins calculations show that traders are taking above 50% of the total profit margin while farmers who are doing all the work of producing vegetables and bearing the associated risks, takes less than 50% of the profit margin. This share disproportion of benefits is the reflexion of poor relationship among actors. Simulation results indicate that the conventional farming system is still economically more attractive to farmers in the Niayes compared to the organic farming system. But, environmental results in terms of GHG emissions show that the organic system is found to be less emitter and more effective in mitigating climate change. Moreover, simulation results also show that there is a "win-win" situation for conventional farmers when they go for crops that required less use of chemical fertilizers and partially adopt organic farming system. Results about risk analysis reveal that producers under both system of production are risk-averse. However, the risk attitude and management are different from one system to another.

Keywords: Sustainable intensification, Climate Change, Organic farming, conventional farming, mathematical programming, Greenhouse gas emissions, vegetable farming, Niayes Region.

Changements climatiques et Intensification Durable au Sénégal: Une Etude de Cas du System de production Biologique des Légumes dans la Zone des Niayes.

Résumé

Dans notre recherche nous avons étudié les systèmes actuels de production et de commercialisation des légumes dans la zone des Niayes afin d'analyser le potentiel de l'agriculture biologique à améliorer la productivité des producteurs et à atténuer les changements climatiques. Un modèle agricole est utilisé pour étudier les performances économiques et environnementales du système de maraichage bio comparé au système de maraichage conventionnel ou classique dans la communauté rurale de Diender. Notre analyse est effectuée dans deux exploitations représentatives (conventionnelles et biologiques). La marge brute est considérée comme un indicateur économique pendant que l'équivalent CO2 est considéré comme un indicateur environnemental. En outre, le modèle Esperance – Variance (E-V) est aussi utilisé pour analyser le risque dans les deux systèmes de production. Ceci est réalisé en effectuant une analyse sur Excel et une programmation mathématique, en utilisant des données décrivant une ferme typique légume bio et une ferme typique de légume conventionnel.

Les résultats de l'analyse de la performance du marché grâce aux marges de commercialisation nous révèlent que les commerçants prennent plus de 50% de la marge bénéficière totale tandis que les producteurs prennent moins de 50%. Cette disproportion des parts bénéficiaires est le reflet d'une mauvaise relation entre les différents acteurs du secteur.

Le résultat des simulations montre que le système de production conventionnel est encore économiquement plus attractif comparé au système de production biologique. Mais les résultats environnementaux en terme d'émission de gaz à effet de serre montrent que le système de production organique se trouve être moins émetteur et plus efficace dans l'atténuation des changements climatiques. En outre, les résultats des simulations montrent aussi qu'il ya une situation « gagnant-gagnant » pour les producteurs quand ils produisent des cultures nécessitant moins d'utilisation d'engrais chimiques et adopte partiellement l'agriculture bio. Les résultats sur l'analyse du risque montrent que les producteurs sous les deux systèmes ont tous une aversion pour le risque. Par ailleurs, l'attitude envers le risque et son management varient d'un système à un autre.

Mots clés : Intensification durable, changement climatique, agriculture biologique, agriculture conventionnelle, programmation mathématique, les émissions des gaz à effet de serre, cultures maraichères, Niayes région.

Chapter 1: Introduction

1.1. Background Information and Context

Climate change and food production systems are among the major challenges currently faced by humanity and agriculture has its role to play in both. Climate is the primary determinant of agricultural productivity and climate change is expected to influence crop and livestock production, hydrologic balances, input supplies, and other components of agricultural systems (Adams et al., 1998). The agricultural sector is the most important economic sector in many African countries. In addition, the majority of the household in developing countries depend on agriculture for their livelihoods and this dependency on agriculture make them more vulnerable to the effects of climate change (IFOAM, 2009). During the next decades, billions of people, particularly those in developing countries, will face changes in rainfall patterns that will contribute to severe water shortages or flooding, and raising temperatures that will cause shift in crop growing seasons (IPCC, 2007). Consequently, farmers will need to adapt by adjusting technologies and practices in order to continue to meet food requirement. However, adaptation may not be feasible in all situations, because, some vulnerable regions lack of adaptive capacity due to constraint on resources such as access to weather forecasts or better seed varieties (Rosegrant et al., 2008). While there is a growing concern about the impact of climate changes on agriculture, another ongoing process in agriculture is its contribution to climate change.

Modern industrial agriculture of the Green Revolution contributes to a great deal to climate change (Mgbenka, 2012). According to the Intergovernmental Panel on Climate Change (IPCC, 2007) global warming causing climate change is due to anthropogenic greenhouse gases (GHGs), which include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In fact, agriculture which is our primary source of food have contributed to the increase in greenhouse gases emissions through activities such as rice production, synthetic fertilizers used, livestock rearing, change in land use patterns like deforestation (Uprety et al., 2012). The sector is said to be the main contributor to CH_4 and N_2O emissions (60 percent and 50 percent respectively), and also to a lesser extend to CO_2(FAO, 2008). According to a report by FAO (2011), agriculture causes approximately one-third of global GHGs when direct energy use, emissions from livestock, the production of fertilizers, pesticides, machinery and equipment as well as soil degradation and land-use changes for feed production are taken into account.

Agriculture is said to be part of the problem, but it is also considered as part of the solution to mitigate climate change through agricultural practices that are climate resilient and environmentally friendly (Middelberg, 2013). In fact, the increasing population and urbanization has serious implication for sustainable development in less favorable areas of developing countries. In addition, rapidly changing consumption patterns and the impact of climate change and environmental degradation are driving limited resources of food, energy, water and materials towards critical threshold worldwide. Consequently, these pressures are likely to be substantial across Africa, where countries will have to find innovative ways to boost crop and livestock production to avoid becoming more reliant on import and food aid (Pretty et al., 2011). Furthermore, there is a need to search for solutions to face the reality of climate change. In the agricultural sector which both emits and sequesters greenhouse gases (GHGs), the importance of mitigating the effects of GHG emissions becomes increasingly significant (FAO, 2011). Mitigation of climate change is defined by IPCC (2007) as a human intervention aimed at reducing the sources or enhancing the sinks of GHGs. Mitigation is a response strategy to global climate change and its total global potential depends on many factors, including emission levels, availability of technology, enforcement, and incentives (Rosegrant et al., 2008). According to Goh (2011), the solution of climate change caused by agriculture lies in selecting the best form of agricultural and farming practices aimed at cost-effective production with minimum adverse effects on the environment and climate. Mitigation of climate change is a global responsibility. In spite of being the most vulnerable to climate change because of their exposure, low incomes and greater resilience on climate sensitive sectors like agriculture (Stern, 2007); developing countries are estimated to account for three-fourths of global technical potential in climate change mitigation in agriculture, with Asian countries accounting for 40 percent, Africa 18 percent, and Latin America and the Caribbean 15 percent (Smith et al., 2007). According to the fifth assessment report of the IPCC, African countries can play a role in global climate stabilization efforts by taking advantages of low carbon options which are not only advantageous but also avoid future emissions. The fifth assessment report further emphasize that the atmosphere is a global commons, and therefore, mitigation cannot be achieve effectively if countries advance their interests independently. Furthermore, to limit greenhouse gases emissions effectively and to address other climate change issues such as building resilience and capacity in regions such as Africa, international cooperation is necessary. Agriculture which is not only both affected by climate change and contribute to it can also adapt and mitigate climate change. Within agriculture, organic production system has great mitigation and adaptation potential. Organic agriculture is a broad set of farming practices that are based on ecosystem management, integrated cropping and livestock systems, diversity of product, and resilience on natural pest and disease control without the use of synthetic inputs (Ziesemer, 2007). Organic agriculture refers to the type of farming that does not use the synthetic chemicals such as fertilizers, pesticides, fungicides, and insecticides or genetically modified seeds in addition to the use of a range of techniques that help sustain ecosystem and reduce pollution, while improving both the production and the quality of nutrition (IFOAM and FiBL, 2006). Therefore, organic farming not only enables ecosystems to better adjust to the effects of climate change, but also offers a major potential to reduce the emissions of agricultural greenhouse gases (FAO, 2003). Organic agriculture offers alternatives to energy-intensive production inputs such as fertilizers which are limited for poor rural populations of developing countries by rising energy price (Mbengka, 2012). According to the Agriculture Food Organization, African countries are said to leak carbon as they erode and lose organic matter due to bad farming practices, but, the same soils could be turned from a carbon source to a carbon sink. Thus, with appropriate farming practices such as organic farming, Africa has a huge potential to mitigate climate change and Senegal is not an exception.

1.2. Problem Statement and Justification

Climate change is one of the most important issues that the world is currently facing. The concept of “Sustainable Intensification (SI)” in agriculture has recently emerged and is becoming a common term much used in discussions around the future of agriculture and food production in the face of climate change. The sustainable intensification is considered as an approach that entails increasing food production from existing farmland in ways that have lower environmental impact and do not undermine food production in the future. Today, several forms or components of sustainable intensification in agriculture are used to adapt and mitigate climate change around the world and Senegal is not an exception. Nowadays, there is a growing concern about the importance of sustainable intensification in food production and organic food production has been given a big importance worldwide with a pressing need to understand the relative economic and environmental impacts of conventional and organic farming methods.

The livelihood of about 77 percent of the Senegalese population depends on small-scale agriculture, which is adversely affected by the consequences of climate change. Senegal has been particularly affected by climatic disturbances and disrupted weather patterns seen across the Sahel since 1973, with unseasonal heat-waves and rains causing recurrent drought in rural areas and flooding in cities (Sall et al., 2011). Further, the soils in Senegal have been on a degrading trend for a long time due to hash climatic conditions, geographic features and man-made causes[1]. Today, there is a growing consensus on the need to proceed to greater changes in agriculture and food systems in order to the world can feed itself, today and in the future, with healthy and nutritionally high quality food, while contributing to fight poverty, preserving biodiversity and naturals resources, mitigating and adapting to climate change in a resource-constraint world (Parmentier, 2014). The country developed its National Adaptation Program of Action (NAPA) in 2006, following the recommendation to least-Developed countries to create policy frameworks that enable them to communicate more clearly about their vulnerabilities and priorities for adaption. This was followed by many other private and public interventions aiming at improving livelihood of vulnerable people through the introduction of various technologies for improving productivity, adapting, and mitigating climate change. Among those technologies, organic farming techniques have been promoted in the Niayes region by an NGO named ENDA-PRONAT since 1986. Studies on organic farming methods reveal that they can increase agricultural productivity and can raise income with low-cost, locally available and appropriate technologies, without causing environmental damage (UNEP-UNCTAD, 2008). Organic agriculture is thus promoted to create integrated, human, environmentally and economically viable agriculture system.

Horticulture (fruits and vegetables mainly) practiced in the Niayes region is one of the most dynamic sectors of agriculture in Senegal, due to the permanence of its activities in certain areas, of the number of practitioners at national level, of the diversity of species grown, and specially to the financial benefits that actors get from it.[2] Further, horticulture is a high-value and dynamic

[1] Source: CSE Dakar-Senegal
[2] Direction de l'Agriculture du Sénégal

sector and is becoming an important export sector in Senegal (Maertens, 2008). With a growing population at a rate above 2% especially in urban centers at the expense of the campaign, there will be a necessity to satisfy the need for food of that population (MPEA, 2006). The horticulture production is one of the sector that use greatly pesticides and fertilizers to meet that demand. The Senegalese market for fertilizer is essentially intended for groundnuts, grain crops, horticultural crops, cotton, and sugarcane production (Fuentes et al., 2012). In the Niayes region, modern agriculture has gradually replaced traditional agriculture by developing a production for marketing. It intensifies the production by the increase use of fertilizers and pesticides that enable the increment of yields in the short term. But the intensification of agriculture associated with population growth and unstable climate conditions (chronic deficit rainfall) reversed the gains of farmers. It is noticeable in different areas of the Niayes the degradation of natural resources with repercussions on all rural activities (production, processing, small crafts). In addition, Senegalese agricultural policies are most often defined without the involvement of actors and without long-term vision that promote the management of climate change. This situation has pushed producers and families of small farmers in a precarious situation that limit their potential for innovation and to improve income from production. The continuing exodus, especially of younger generation to urban centers has reduced the potential of rural areas. This context led ENDA PRONAT to implement programs to stimulate change towards a healthy and sustainable agriculture, thereby increasing the profitability of agriculture through organic farming techniques and to better secure natural areas and biodiversity.

However, despite the efforts made in the development of sustainable agriculture systems and its potential to both mitigate and adapt to climate change, the promotion of organic farming in West Africa and in Senegal have not yielded the desired results. In fact, organic agriculture is far more developed in North, South and Eastern Africa than in other region of Africa (UNEP-UNCTAD, 2008). In Senegal, there is still little known about the actual economic and environmental impact of organic agriculture, especially in the horticultural sector. Therefore, after more than a decade of implementation, it is legitimate to assess the attractiveness of this farming type in both mitigating climate and enhancing farmers' productivity. In order to fill the knowledge gap, this study develops a bio-economic whole farm model to investigate the potential of organic agriculture to both mitigate climate and enhance farmers' productivity in the horticultural production system of the Niayes region in Senegal.

1.3. Research Objectives, Questions and Hypothesis

1.3.1. Research objective

Overall Objectives:

The overall goal of this study is to investigate the present production and marketing systems of vegetable in the Niayes so as to analyze the potential of organic farming to enhance framers' productivity and to mitigate climate change.

Specific Objectives:

Consideration of the general objectives above led to the following specific objectives:

- ✓ To conduct a detail investigation of the current status of production and marketing systems of the vegetable industry in the Niayes Region.
- ✓ To analyze the economic performances of organic vegetable farming system compared to conventional vegetable farming system;
- ✓ To analyze the environmental performances of both conventional and organic vegetable farming systems;
- ✓ To analyze risk in conventional and organic vegetable farming in the Niayes;

1.3.2. Research Questions

1. What is the current status of production and marketing systems of the vegetable industry in the Niayes Region?
2. What are the economic performances of organic farming techniques compared to conventional systems?
3. Which system of production is more effective in mitigating climate change through a carbon emission equivalent reduction?
4. What is the level of risk associated with the production and marketing of vegetables under organic and conventional farming systems?

1.3.3. Research hypothesis

1. Vegetable farming and marketing are dynamic economic activities in the Niayes;
2. Organic farming techniques can be an attractive enterprise as much as conventional farming for farmers in the horticultural sector in the Niayes;

3. A policy seeking a reduction of carbon emissions is more effective in organic farming system compare to conventional farming system;
4. There is a high variability of risk between the two systems;

1.4. Approaches and methods of the study

Organic farming as an agricultural technology have been adopted by some vegetable farmers in the region of Niayes in order to adapt/and or mitigate climate change, to improve revenue, but also for a better human and soil health systems. To investigate the attractiveness of this farming system compared to the conventional existing system, Mathematical programming models are used to simulate both economic and environmental performances of the two systems of production. In addition, a farm risk programming models based on the Esperance-variance (EV) model is used to analyse risk attitude in the two farming systems.

1.5. Relevance of the study

The main negative impact of climate change is the emission of GHGs which are directly or indirectly due to human activities through the burning of fossil fuel and agriculture practices. Today, the world is searching for solutions to a series of global challenges and the conventional food production system is one of them. With the growing pressure on our natural resources, policy makers are looking for production systems which produce more outputs with more efficient use of all inputs on a durable basis, while reducing environmental damage and building resilience. Organic farming systems are said to be a concrete and sustainable option to that issue. Generally, climate change and variability are considerable treats to agricultural communities, particularly in developing countries such as Sub-Saharan African countries. Agriculture through food production and distribution is also said to be a big contributor of GHG emissions. So while agriculture is part of the problem, it is also part of the solution. Exploring the economic and environmental effect of organic farming in the face of climate change of a growing agricultural sector like the horticulture production may gives more insights for policy makers to design strategy in agro-environmental policies in Senegal. The perspective of this study is the sustainability of the horticultural sector activity, in economic, social and environmental meaning.

1.6. Outline of the thesis

This thesis is structure into six chapters. First of all, Chapter one which is the general introduction provides the background information and context of the study. Chapter two presents a general overview of the status of vegetable farming in the Niayes region and how vegetable crops are produced and marketed. Chapter three concentrates on the literature to cover theoretical and empirical issues necessary for the thesis. Chapter four presents the study area and the method used in this study. Through Chapter five the results of the study are presented and discussed. Finally the conclusion, recommendations and opportunities for further research are covered in chapter six.

Chapter 2: Context and General Observations of the Vegetable industry in the Niayes Region

This chapter is structured into two parts. The first part gives a quick overview about vegetable production and its evolution in the Niayes region. The second part provides qualitative and quantitative information on the production system and the distribution pathways of irrigated vegetables within two farming systems in the Niayes area in Senegal.

2.1. Historic overview of vegetable production in Senegal

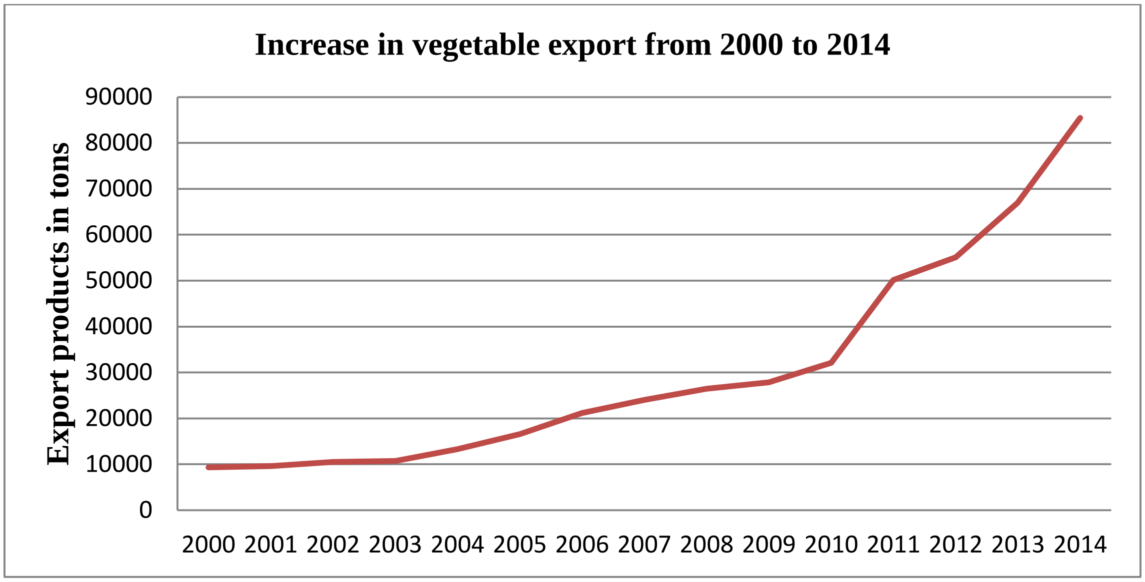
Horticulture is defined as the art and science of growing fruits, vegetables, herbs, nuts and ornemental plants (such as trees, shrubs, flowering plants and turf). Horticulture (mainly vegetables and fruit production) in Senegal is an ancient activity. Firts settled in the nineteenth century in the Cap Vert Peninsula (current Dakar). The first technical recommendations for vegetable crops in Senegal date back to 1911 (Direction de l'Horticulture, 2014). The activity is now practiced in all region of Senegal. During the drought of the 70s and 80s, many farmers turned to irrigated horticultural activities. Most of them have settled in the Niayes area, and in the delta of the Senegal River Valley, as well as around Tambacounda, Kolda, Sédhiou and Ziguinchor. After 1984, the Senegalese government started to promote horticulture as a vehicle of agricultural development. A comparative study by Seck and Sidibé (1991) on horticulture and food products shows the financial advantage of horticulture compared with the cultivation of cereals and groundnuts. Between 1992 and 1993, the government developed a master plan to deal with some of the constraint of the horticultural sector.

Founded in 1995, TROPICASEM is the largest vegetables seed company in Senegal and the only private company in West Africa that conduct research to improve vegetable varieties. In recent years, TROPICASEM has developed a large number of varieties of eggplant, carrot, okra, lettuce, and onion which have been subject to mandatory testing by ISRA.

After 2000, the government of Senegal has adopted a new set of policies to modernize and intensify the agricultural sector, crop diversification, food security, poverty reduction, access to foreign market and rising income. The policies that illustrate those objectives include the Declaration of Agricultural Development Policy (PBDD), the Law of Orientation Agro-Sylvopastoral (LOASP), the RVA plan (Return towards Agriculture), and the great Agricultural Offensive for Food and Abundance (GOANA) (Ndiaye, 2011).

The huge production base of some vegetables (mainly beans and cherry tomato) offers Senegal great opportunities for export. Since the 1990s, the export of horticultural products from Senegal has increased sharply; from less than 2000 ton in 1991 to almost 16,000 ton in 2005 (Maertens, 2008). Vegetable exports have increased in terms of value, with an average annual growth rate of 16.3% and a peak of 70% from 2010 to 2011, demonstrating an increasing interest for off-seasonal vegetable production among international trading partners (ANSD, 2011). Between 2004 and 2014, horticultural export increased from 13,321 tons to 85,414 tons (see figure 2.1) (World Bank, 2014). A part from some minor volumes to neighbouring countries, these exports go to the European Union, mostly to France (40% of the exported volume), the Netherland (35% of the exported volume) and Belgium (16%). The growth in vegetable exports in Senegal was coupled with the development of a modern agro-industry, implemented by local and foreign investors. In addition, the horticulture agro-industry interacts with the rural smallholder economy by sourcing part of the produce from local small farmers and by hiring labourers from local farm households. However, horticultural export in Senegal faces a great challenge which is related to the non-compliance with quality standards, including sanitary and phytosanitary (SPS) standards. In fact, a wide range of pesticides (mainly methamidophos, dicolfol, dimethoate, sulphur, and tamaron) is being use to control pests and diseases in the Niayes. Consequently, the over-use of pesticides is becoming a real threat to the quality of fresh vegetables and to public health. As a result, vegetable export is limited to only those productions that meet standards while the Niayes areas is offering very good agro-climatic conditions. The figure below shows the evolution of vegetable export in Senegal from 2000 to 2014. The overall trend is accelerating. Therefore, with this huge production opportunity there is an urgent need for the government to support farmers to meet standards in order to be able to export their products without constraints.

Figure 2.1: Annual vegetable exports in Senegal



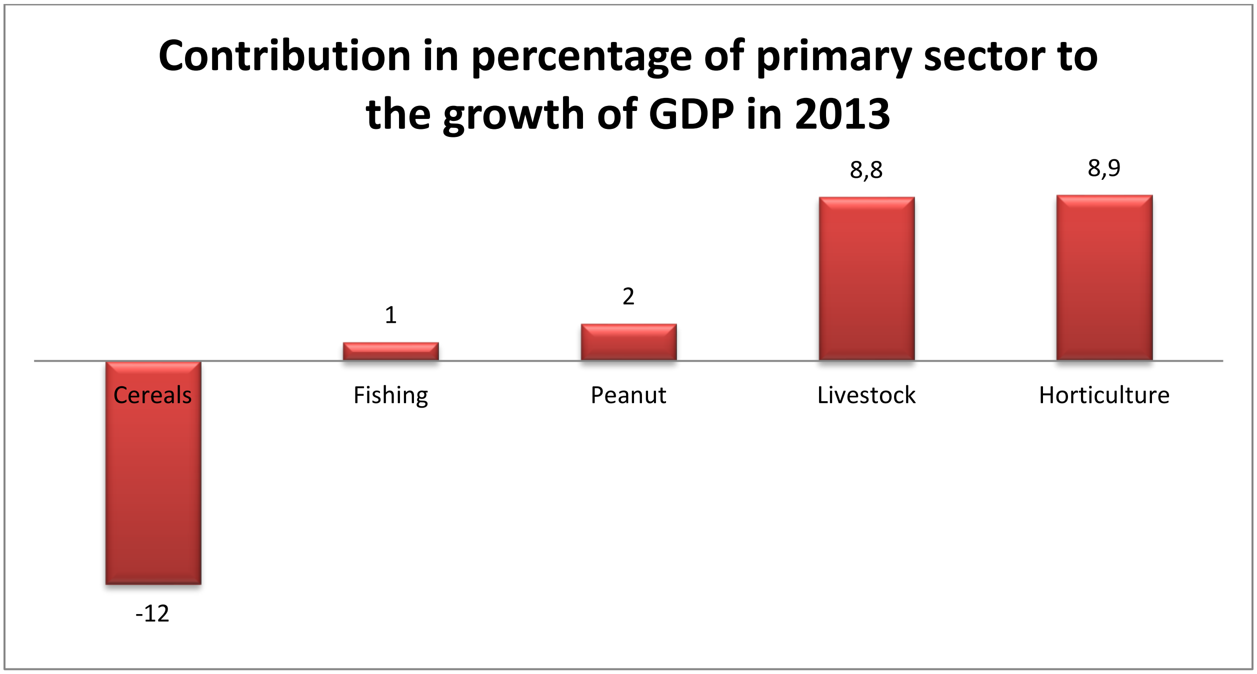
Source: World Bank, 2014

2.2. Current status of agricultural/Vegetable Farming systems in the Niayes

2.2.1. Situation and Economic potential of vegetable farming in the Niayes Region

Agriculture plays an important role in the socioeconomic life of Senegal. However, its contribution to GDP growth has decreased by 0.8 points, from 1.3% in 2009 to 0.5% in 2010 (ANSD,2011).Moreover, the horticultural industry has been ranked as the best performing sub-sector of Senegalese agriculture in a context where agricultural productivity has declined in recent years. The sector has been supported by a strong increase in foreign direct investment in its export-driven component. This sub-sector has contributed about 8.9 percent to GDP growth in 2013 (see figure 2.2) (World Bank, 2014). In addition, it is an activity that not only contributes to meet food needs but also improves farmers' incomes. The fruit and vegetable intake by Senegalese adult is high compared to other major sources. Fruit and vegetables comprised 42% of all other foods (Anderson et al., 2010).

Figure 2.2: In the primary sector, Horticulture is the largest contributor to GDP growth.



Source: DPEE, note de conjoncture, 2013.

The vegetable sector occupies the most important part among the horticultural crops, about 65% in 2000 (UE/CEDEAO, 2012). Production volumes of the vegetable sector in Senegal have grown rapidly over the last decade. However, the growth potential of the sector is far from being achieved, as climate conditions of the Niayes area are very favourable to vegetable farming. Therefore, the government expect that horticulture will continue to improve the development of the agricultural sector in Senegal.

The Niayes area also enjoys a favourable geographical advantage as it is located near cities like Dakar, Thies, and Saint-Louis with an important migration of seasonal labour forces. The performances recorded in the horticultural sector are the result of efforts by the Senegalese government through its various program and project, by non-governmental actors and abova all by the producers themselves (Ndoye et al., 2004). From 2004 to 2013, the area and production level of vegetables increased significantly (see table 2.1).

Table 2.1: Evolution of the production of major vegetable crops in tonnes, from 2004 to 2013

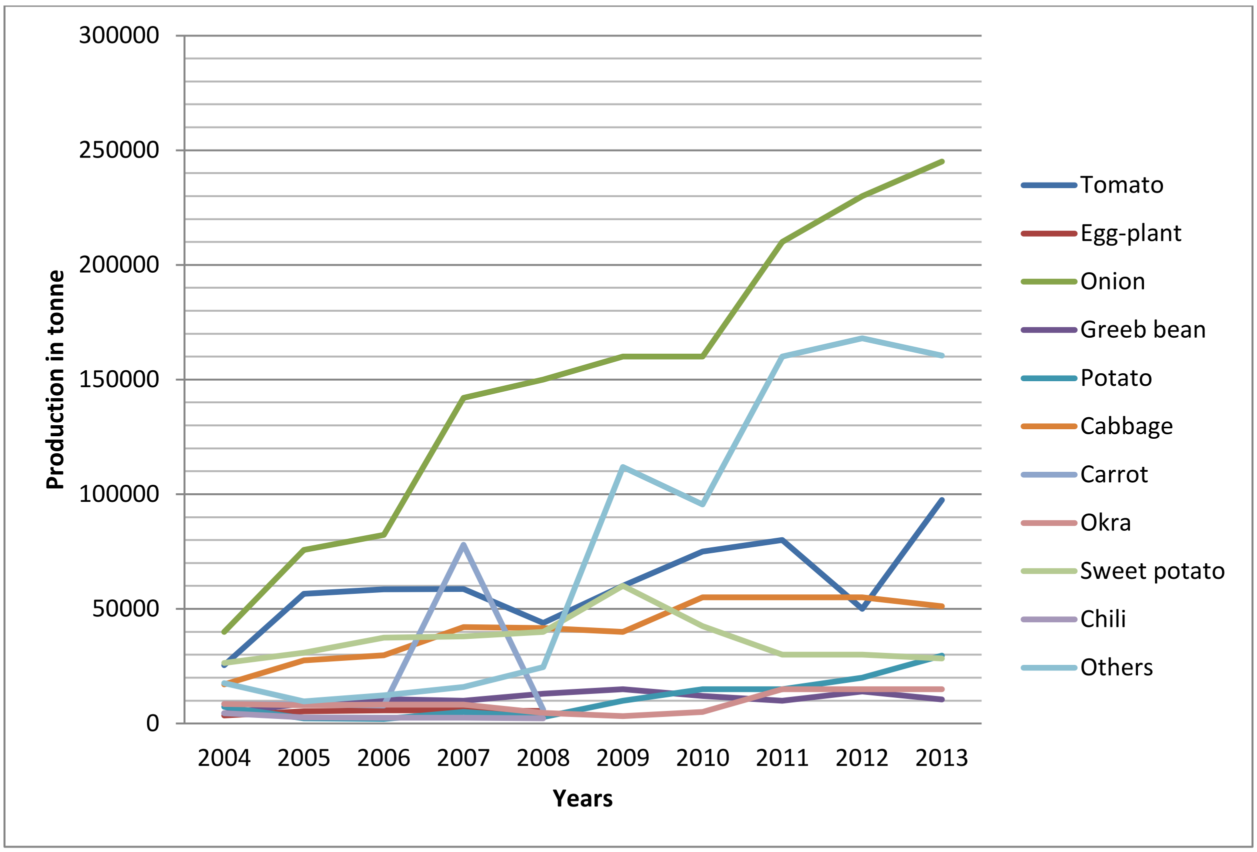
Crops	YEARS									
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Tomato	25375	56520	58550	58600	43820	60000	75000	80000	50000	97513
Egg-plant	3454	5396	5770	5800	5455					
Onion	40000	75641	82300	142000	150000	160000	160000	210000	230000	245000
Green bean	4500	8711	10600	10000	13000	15000	12000	10000	14000	10500
Potato	7282	2323	2010	5000	2825	10000	15000	15000	20000	29680
Cabbage	17000	27574	29700	42000	41650	40000	55000	55000	55000	51182
Carrot	8506	8438	7850	78000	5963					
Okra	8500	7920	8300	8300	4700	3200	5000	15000	15000	15000
Sweet potato	26485	30875	37500	38000	40000	60000	42500	30000	30000	28350
Chili	4463	2723	2510	2500	2280					
Others	17598	9649	12250	16000	24615	111800	95500	160000	168000	160500
Total production (ton)	**165167**	**237775**	**259346**	**408207**	**336316**	**462009**	**462010**	**577011**	**584012**	**639738**

Source: Direction of Horticulture (Senegal)

The production comes mainly from the Niayes areas (Dakar, Thies, Saint-Louis, and Louga). The main vegetables grown in off-season (from October to July) are onion, tomato, carrot, green beans, egg-plant, cabbage, turnip and bitter eggplant. The achievement in research on certain species has made it possible for the following vegetables to be growing in rainy season: sweet potato, okra, cassava, pumpkin, sorrel, cabbage, tomato, eggplant, and bitter eggplant. In 2012, the gross production of vegetables was estimated about 675,000 tons; including 210,000 tons of onion, 15,000 tons of potatoes, 8,340 tons of carrots, and 160,000 tons of tomatoes (Direction of Horticulture, 2012). The production is primarily intended for urban centres that are the biggest vegetable consumption areas. Dakar the capital city which occupies only 0.3% of the national territory comprising 21% of the population is the priority destination of vegetable products. According to a study by Mbaye and Moustier (2000), 45% of the production of vegetables is marketed at Dakar. Besides, a big proportion of the production is destined for exportation mainly in European countries. Vegetable exports from the country in 2012 exceeded those of 2011 and mark a significant increase over previous years. They are estimated at 56,778 tons in 2012 against 51,270 tons in 2011. The growth of vegetable export in Senegal is the result of an association with the development of modern agro-industry, build by local and some foreign investors in response to opportunities created by an increasing demand of EU countries (Maertens, 2008).

Vegetable production is concentrated mainly during the cold-dry season (from November to March) because the production in the rainy season is difficult due to high presence of parasites which significantly affect yield. This concentration of production during a specific period of the year has led to an imbalance situation in the market where supply sometimes is greater than the demand. This situation causes large fluctuations in sale prices which entrain income loses for producers. The figure below shows the evolution of vegetable production at national level recorded from 2004 to 2013. The overall trend during this decade is increasing for all vegetables considered. The figure shows also that onion is the most grown vegetable follow by tomato and cabbage.

Figure 2.3: Annual vegetable production in Senegal



Source: Direction of Horticulture

The Niayes region offers huge potentials for economic development due to its position near major urban cities (Dakar, Thies, Saint-Louis, and Louga) and its environmental conditions. In addition, due to its favourable agro-ecology and availability of irrigation water, the Niaye region is very suitable for vegetable farming. However, various agronomic and environmental studies have highlighted the major constraints to the development of the sector. The majors constraints identified are the water table depletion and salinization, and land degradation. In addition, rapid urbanisation is reducing the arable land. Another concern is the marketing of vegetables because of their seasonality and perishable character. Besides, the main problem for Senegalese horticultural export is its quality due to sometime improper use of pesticides by farmers in the Niayes zones. Despite the effort made in regulating the marketing of pesticides in Senegal, horticultural producers are still not able to meet SPS norms required by the UE market (Mbaye, 2005).

2.2.2. Vegetable production and climate change in the Niayes Region

More erratic rainfall patterns and unpredictable higher temperature are two major parameters of climate change that has far reaching implications on agriculture in general and horticulture in particular (Datta, 2013). According to FAO (2004), latitudinal and altitudinal shifts in ecological and agro-economic zones, land degradation, extreme geophysical events, reduced water availability, rise in sea level and land salinization are postulated. Vegetable crops are very sensitive to climate vagaries and sudden rise in temperature as well as irregular precipitation at any phase of crop growth can affect the normal growth, flowering, pollination, fruit development and subsequently decrease the crop yield (Afroza et al., 2010). Therefore, the effects of elevated temperature and unpredictable and irregular precipitation can disrupt the normal growth and development of plants.

In Senegal, climate change is characterized by a reduction and increased variability of rainfall, and an increase in temperature. For example, the average rainfall in the period 2000-2009 has fell by 15% in reference of the period 1920-1969 (OXFAM, 2013). The population of Senegal has increased by 64% between 1990 and 2010 with the largest increase occurring in Dakar, Thies, and Kaolack (CIA, 2011). This population expansion has many implications for sustainable development as this will increase pressure on limited natural resources.

When asked about climatic trends, farmers have asserted that the last fifteen to twenty years have been marked by a high degree of irregularity in the weather, with frequent dry spells at crucial period of the agricultural cycle or untimely rain that damage crops just as they have matured. This situation has led farmers to stop cultivating crops such as millet or sorghum and turned into vegetable gardening. However, even though horticulture has been considered as a form of adaptation for rain fed farmers in the study area, the sector is also affected by climate change. In fact according to farmers interviewed, salinity is one of the serious problems faced by producers. It is estimated that about 20% of cultivated land and 33% of irrigated agricultural lands worldwide are afflicted by salinity (Foolad, 2004). The Niayes region is not an exception because many parts of its areas are affected by salinity. Onion is recognized to be more sensitive to saline soils while other crops such as tomatoes, eggplants and peppers are less sensitive (Spaldon et al. 2015).

2.3. Production and marketing channels of conventional and organic vegetables in the Niayes Area.

2.3.1. Vegetable production in the conventional and organic farming systems in the Niayes Region

In the Niayes area, organic and conventional farmers produce a variety of vegetables; where each kind is cultivated in a separate plot and through a rotation system. The main crops cultivated are tomato, green bean, potato, eggplant, cabbage, onion, lettuce, carrot, okra, chili, and "bissab" (Hibiscus).

Irrigation is practiced, either by capturing surface groundwater from well through manual means or motor pumps, or by means of subscription to the water distribution network of the Senegalese company (SDE), which is quite expensive. The method of irrigation that is mostly used remains the manual system which represents about 82% of farmers in the area (Direction of Horticulture, 2012). Other methods such as gravity irrigation system (0.6%), drip irrigation system (0.9%), and sprinkler irrigation system (1.3%) are not very popular because they are costly. The table below shows the irrigation system used in the horticultural farms in different locality in the Niayes area. A study by the Direction of horticulture in 2014 shows that the way irrigation is practiced in the region is leading to a huge waste of water and energy. In fact, the study found that the quantity of water applied in a plot by farmers exceeds four to six times the requirement recommended. In addition, watering is done daily without technical consideration. The farmer rarely integrates the management of water in the conduct of its irrigated area because water is usually not considered as production factor, but rather as an inexhaustible source.

Table 2.2: Distribution of horticultural farms by rural community and the method of irrigation used

	Manuel irrigation system	Gravity fed irrigation system	Sprinkler irrigation system	Drip irrigation system	Other irrigation systems	Total number of exploitation
Bambilor	84,5	1,5	7,2	0,8	6,0	**1443**
Diender Guedj	60,6		0,9		38,5	**2209**
Keur Mousseu	31,0	0,5	2,8	14,5	51,3	**400**
Fandène	83,0			2,1	14,9	**47**
Notto Gouye Diama	65,4				34,6	**234**
Taiba Ndiaye	42,2	10,3			47,5	**282**
Darou Khoudoss	93,0	0,1	0,1	0,1	6,8	**1710**
Méouane	100,0					**24**
Kab Gaye	99,7				0,3	**339**
Diokoul Ndiawrigne	98,7				1,3	**468**
Thieppe	98,4			0,3	1,3	**695**
Bandeigne	100,0					**25**
Léona	97,3			1,0	1,7	**1251**
Ndiébène Gandiol	98,8			0,6	0,6	**808**
Gandon	97,4	0,9			1,8	**228**
Total	**82,2**	**0,6**	**1,3**	**0,9**	**15,0**	**10163**

Source: Direction of Horticulture / 2012

Seed, fertilizers and phytosanitary are delivered to small stores near to the production areas. Equipments are usually limited to watering cans, some rudimentary farming equipment, equipment for phytosanitary and treatment, and in some rare cases tractors and motors pumps. The table below outlines the number of agricultural equipment used by producers in the Niayes zone during the 2011/2012 campaign. The material is evaluated according to the status of use of each type of equipment (property, co-ownership, loan, and rental). The table shows also for each category of equipment or installation, the total number of producers who actually use them during the campaign. Finally, in the last column the table shows the average number of equipment by producer according to each type, calculated according to the number of units owned or co-owned. We found a relatively comfortable level of equipment for certain types of equipment or installation such as billioneuse, refrigerated trucks, small equipment, cold rooms, storage shops, etc.

Table 2.3: Distribution of materials, equipment and production facilities in horticultural farms in the Niayes areas

Type of Equipment	Number of producers	**Material status**			Total number utilized	Average number per producer
		Owned or co-owned	Rented	Borrowed		
Equipped tractor	2293	91	2604	43	2738	0,3
Offset	1652	44	2351	25	2420	0,4
Billonneuse	219	22	653	5	680	2,8
Pulverizer	6737	10809	118	1290	12217	1,6
Plow	765	22	1276	76	1374	1,7
Refrigerated trucks	38	2	177	1	180	4,7
Cart	4913	2096	6113	338	8546	1,3
Small Equipment	9000	83542	241	1119	84902	9,3
Cold storage	53	2	159	0	161	3,0
Warehouse	701	283	1561	3	1847	2,6
Processing Units	2	3	0	0	3	1,5
Serre tunnel	61	1073	0	0	1073	17,5

Source: Direction of Horticulture/2012

Horticultural farmers in the Niayes use a fairly large workforce at all stages of the production process. The labour structure is shown in table 3.3 below. The gender structure shows a low representation of the female paid workforce. However, they are well represented within the family labour catergory (54% for harvesting and packaging, 44% for sowing and 28% for management) and in the category of temporary employees (59% for the harvest and packaging, 39% for sowing and 38% for the management work).

Table 2.4: Distribution of workforce by category according to task performed and sex

Workforce category	tasks	Male enrolment		Female enrolment		Total enrolment
		Number	Percentage	Number	Percentage	
Family labour	Land preparation	23099	84,1	4377	15,9	27476
	Sowing or transplanting	32373	55,7	25740	44,3	58113
	Spreading manures	19404	81,4	4425	18,6	23830
	Water spray	19035	86,3	3013	13,7	22048
	Plant treatment	15305	92,0	1328	8,0	16634
	Other management work	23867	61,6	14899	38,4	38766
	Harvesting or packaging	36617	46,7	41749	53,3	78366
	Other works	16838	68,8	7639	31,2	24477
Permanent employees	Land preparation	7617	100,0	0	0	7617
	Sowing or transplanting	10531	98,3	177	1,7	10708
	Spreading manures	10541	99,8	25	,2	10566
	Water spray	9464	99,8	23	,2	9487
	Plant treatment	9101	99,4	57	,6	9157
	Other management work	9592	98,4	156	1,6	9747
	Harvesting or packaging	10499	88,1	1420	11,9	11919
	Other works	7667	97,8	88	1,1	7842
Temporary employees	Land Preparation	17942	94,5	984	5,2	18994
	Sowing or transplanting	18998	60,7	12292	39,3	31290
	Spreading manures	13141	94,7	687	4,9	13874
	Water spray	13929	95,5	607	4,2	14583
	Plant treatment	12555	99,4	31	,2	12632
	Other management work	16528	61,7	10242	38,3	26771
	Harvesting or packaging	27381	40,5	40161	59,4	67589
	Other works	14505	82,6	3011	17,1	17563

Source: Direction of Horticulture / 2012

To achieve high production yields and income, vegetable farmers in the Niayes area use huge amount of synthetic fertilizers and pesticides. However, the continuous use of high amount of these inputs can lead to a reduction in crop production, deterioration in the quality of natural resources and the ecosystem. The increasing awareness about the negative impact of the increasing use of synthetic fertilizers and pesticides on public health but also on the environment has lead some farmers in the Niayes to turn into organic farming system. Organic farming offers a solution for sustainable agriculture and help to safeguard the ecosystem. However, from an economic perspective, the conversion from conventional farming to organic farming can be a lengthy process during which farmers may incur a loss in income (Sudheer, 2013).

2.3.1.1. The Conventional Farming System

Conventional farming which is also sometimes described as industrial agriculture is a system of production based on the use of synthetic chemical fertilizers, pesticides and sometimes genetically modified organisms (GMO). With this system of production it is possible to produce much larger quantities of food, on less land.

Agriculture in Senegal as in other Sub-Saharan African countries uses less chemical fertilizers and pesticides than other regions of the world. In the Niayes area which is the main place of production and supply of horticultural products, chemical fertilizers and pesticides are increasingly used. However, many studies have shown that the way that farmers use these inputs as well as the lack of knowledge on how to use them properly and the lack of proper equipment were shown as being a principal factor of risk on public health and the environment (Cissé et al., 2006).

Types of conventional vegetable farms in the Niayes

There are three types of vegetable farms according to the size and the management:

- *Small farms:* Their sizes are usually less than one hectare and are more individual farms than family farms. This individual character is usually linked to the way that land is owned in the area. In fact, these farms are often fragmented plots that their owner rent to national or migrants from the sub-region (especially from Guinea or Mali). These farms are often located at the periphery of Dakar city (Pikine and Rufisque). In this type of exploitation, the mobilized work forces exceed rarely two persons and use traditional irrigation techniques. The basic investment is very low and consists of digging a well as small operating equipment. This type of exploitation is also characterized by the non-diversification of the production and low income due to land constraint. The main crops are lettuce, onion, eggplant and tomato and are intended to local market only. However, the use of pesticides and synthetic fertilizers is very low in such farm types.
- *The medium-sized farms:* they are found at almost all the Niayes zone and are usually family style. Their size varies a lot and can exceed 5 ha. The irrigation system is more sophisticated compared to the one use by the small farms with the evolvement of motorized pumps. It can be found a large number of pumps with speeds of up to $50m^3/hr$. Those exploitations that do not have pumps involve a large number of workforces consisting of family labour and hired labour ("Sourgua"). The system of sharecropping is very developed in this type of exploitation where the owners share a portion of the yield

with the “Sourgua” according to a pre-arrangement basis. Some of these farms are private; owners have acquired them by inheritance, purchase, donation or lease. They are quit modern types and use mechanical tools to work the land as well to drain and irrigate the field. The production is more diversified and intended for wholesale market and for export. The main crops are tomato, onion, green bean, eggplant, chilli, and cabbage. These farms use significant quantities of chemical fertilizers and pesticides compared to the small farms. Famous solidarity systems called “Santanné” (which consist of calling neighbour workforces for the harvest) help this system of exploitation to reduce some cost of production.

- *Modern or large farms:* they are characterised by their size which exceed 10 hectares and mobilized a very large work force consisting of skill workers. They often hire seasonal workers especially during the harvest periods and their production consists largely of export crops such as tomatoes and green beans. Operators are usually private actors with a larger financial capacity that gives them more advantage in hiring labour compared to those operating in the medium farms who have sometimes difficulty to hired labour at pick periods. Actors operating in this farm types have more access to land due to their social position. They also benefit from an efficient production system which use modern irrigation techniques (like drip system) that allow them to develop fruit production too. There is also a high use of chemical fertilizers and pesticides in this production type. However, compared to small and medium farmers, the mastery of production techniques help to avoid the misuse of those products. In fact, it has been reported a number of health cases issue related to the misuse of synthetic fertilizers and pesticides in the medium farms specially. Most of Senegalese producers do not meet the international standards on pesticides use leading to a restriction in exported products.

2.3.1.2. The organic Farming System

The ecological approach is increasingly recognized by farmers as a sustainable solution to agricultural development and the development in its broadest sense. Nowadays, many non-governmental organizations and farmers have adopted organic farming which is a system of production that rely on crop rotation, animal and plant manures as fertilizer.

Senegal has placed the agricultural sector and private investment in agriculture at the center of its strategy for economic and social development. Currently, the institutional basis of local agriculture is mainly based on non-governmental organizations, farmers ‘associations and other association of professional.

A few non-governmental organizations (such as Enda-Pronat) are promoting a more sustainable type of agriculture. They conduct an awareness campaign on the dangers associated with the misuse of synthetic fertilizers and pesticides in several agro-ecological regions of Senegal especially in the Niayes region. The organic farming system has been introduced in Senegal in the early 80s through non-governmental organization among gardeners especially in the Niayes region. These plots rarely exceed one hectare, belonging mostly to one or more groups of women with a few dozen members (Hane et al., 2001). Despite the investment and effort made to develop this farming system, organic farming is still very marginal today. For some it symbolizes a return to old and traditional practices in a context where the Senegalese government wishes to modernize agriculture. The change in attitude towards organic farming has started in the early 2000 with a commitment of the new government towards sustainable agriculture. Many initiatives have been taken to develop the sector but organic agriculture is not taken into account by the Ministry of agriculture as there is no dedicated structure or referent (OIT, 2013).

In Senegal, organic farming is mainly practiced by small farmers with small land holding. Most of them combine rainfed and irrigated crops. The main principles of this farming system are the diversification and crop rotation, soil restoration by enhanced organic matter and cover crops. In the vegetable sector, the techniques taught are focused on crop diversification, compost, agro-forestry and rotations which can help fix nitrogen and organic matter in the soil and green pesticides.

Types of organic farms in the Niayes

One can distinguish two types of organic farms according to the size and the management:

- *Small farms:* they have the same characteristics as for conventional farms except for fertilizers use, plant treatment, and the management system. Organic farmers use composts and manures (mainly cow, poultry and horse manure) and natural home-made products (basically from Neem extract and other botanical extract) for treatment with the exception of the *bio-beat* which is a biological product formulated commercially by the agrochemical industry. The main crops grown by the small organic farmers are onion, tomato, eggplant, cabbage, and lettuce. In this type of exploitation, we found mostly women whose capacity of production and financial means are very limited.

- *The medium-sized farms:* they are also family types and contrarily to the conventional farming system, the farm sizes do not exceed 5 ha. This is due to the difficulties faced by organic farmers such as the availability of organic matter for compost, maturation time of organic crops, pest attack from neighbouring conventional farms, lack of good quality vegetable seeds, non- existence of local organic market. All these issues limit organic farming. They also use high quantity of manure which is rare at some period of the year, because livestock farming is not very developed in the area. As for conventional farmers, some of the organic farmers also use pumps for the irrigation and hired additional labour forces to perform tasks at peak periods. One interviewed organic farmer, with the help of Enda Pronat and another NGO uses wind power to lift water for irrigation. It is environmentally friendly system, but costly.

2.3.2. Value chain analysis of vegetables in the Niayes

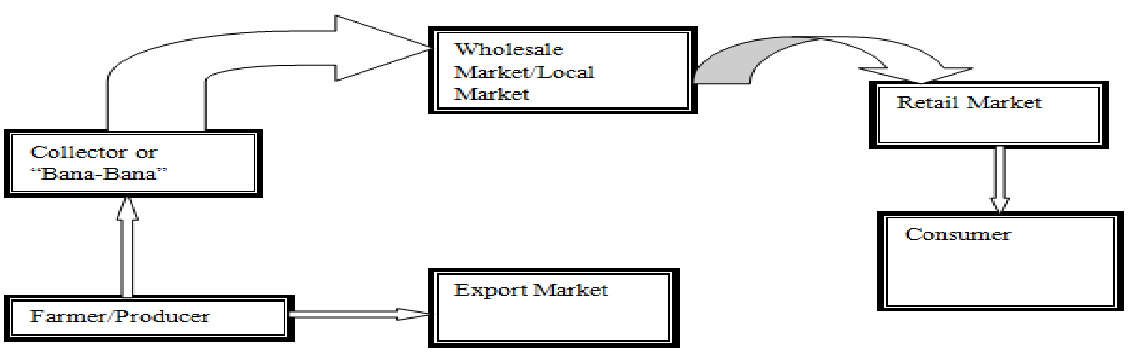
According to Kaplinsky and Morris (2000), a value chain is the full range of activities required to bring a product or a service from conception through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final customers, and final disposal after use. Value chain actors are individuals or institutions that conduct transactions around a particular product as it moves through the value chain. These actors include farmers, traders, processors, transporters, wholesalers, retailers, and final consumers.

Vegetables play an important role in the Senegalese diet. They are the third most important foodstuff after rice and fish. The major actors in the circulation and distribution of fresh vegetables in Senegal are producers, collectors, wholesalers, retailers, and export organizations. Along the chain, each marketing actors can take over one or more functions such as transportation, storage or distribution. The vegetable market is characterized by the seasonality of the production and occasional overproduction. Supply fluctuates widely resulting in prices volatility. The overproduction situation is mainly due to the fact that farmers lack the technical skills and infrastructures to store, process and transport the produce.

Local markets offer a number of opportunities for a diverse range of fresh vegetables. However, the purchasing potential of the majority of Senegalese households is small. Organized and modern distribution network are poorly developed and several imported products compete with local production.

Market flows for vegetable in Senegal are functioning as shown in figure 3.1. Farmers are the primary actors in the agricultural value chain. Collectors ("Bana-Bana") collect the products from producers and deliver the products to the wholesale market. The products from wholesale markets are supplied to retailers and then to consumers. The number of steps for commodity to reach consumers depends upon the product, the location of the market, the type of producers (small, medium, and modern).

Figure 2.4: General structure of vegetable flows in Senegal

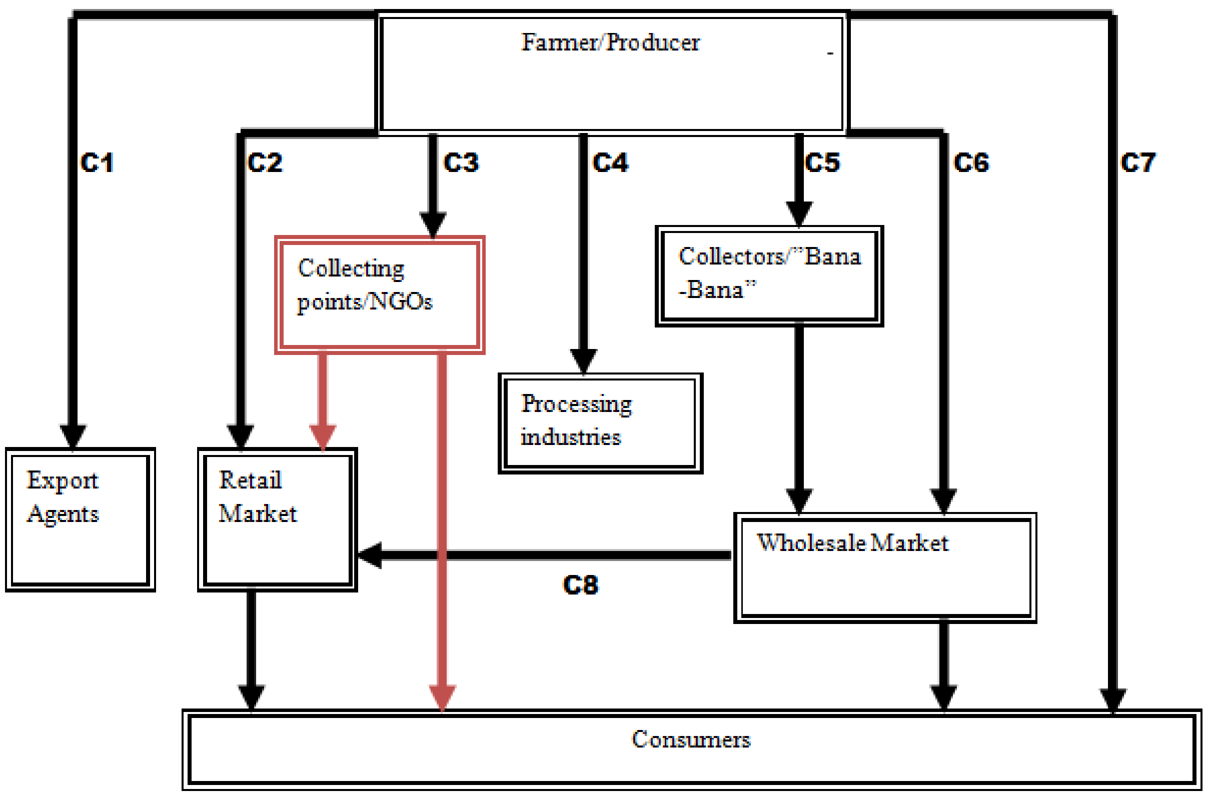


Source: survey data

2.3.2.1. Marketing channels

According to Kokler and Amstrong (2003), a marketing channel is the business structure of independent organizations that reach from the point of product origin to the consumer with the purpose of moving products to their final consumption destination. The analysis of marketing channels is a concrete way to show the flow of the goods and services from their origin (the producer) to the final destination (the consumer).

Figure 2.5: Common flow (Marketing channels) of vegetables in Senegal



Source: Own sketch based on the market survey,(May, 2015).

Note: Red line denotes the flow of organic vegetables when they are sold at premium price and C1 up to C8 stand for channel one to channel eight where:

C1. Producers → Consumers

C2. Producers → Retail markets → Consumers

C3. Producers → Collecting points/NGOs → Consumers

C4. Producers → Processing industries

C5. Producers → Wholesale markets → Consumers

C7. Producers → Consumers

C8. Producers → Wholesale markets → Retail markets → Consumers

The major actors in the distribution of fresh vegetable in the Niayes region in Senegal are producers themselves, collectors, wholesalers, retailers and export agents. The conventional production is sold mostly at the local market either by producers themselves or by collectors. Some small farmers sell their production directly to the consumers. They usually send directly their small amount of products to the market and sell them on small tables or on the ground. Quantities often do not exceed a few kilograms, and vegetables are sold in small piles or per kilo in some cases. Medium producers sell their products at the farm gate to collectors or at the market place by using scales to weight the production packed in bags. But, only farmers with means of transport send directly their production to wholesalers, retailers or directly to consumers. Since transportation is a major problem in the marketing of vegetables, most vegetable growers are limited to their local village or neighboring market where competition with other producers is high. As it is shown in the figure 3.2 above, seven main alternative channels were identified for conventional vegetable marketing. On the other hand, eight main alternative channels for organic vegetables were identified. Contrarily to conventional vegetables, organic vegetables flow also to collecting points that enable them to be sold at premium price. There is no specific market place to market organic vegetables in Senegal. Organic products follow almost the same flow as conventional vegetables. The only difference between the two systems is that there are some specific collecting points for organic vegetables. Some NGOs that are promoting organic farming in the area are helping organic farmers in marketing some of their products and try to offer premium prices. They try to get command from private consumers, restaurants, hotels ready to buy organic products at a premium prices and then collect the command at collecting points located at the local market of some villages. Some producers deliver their products directly to some NGOs' office in Dakar on a weekly basis. However, only a small portion of their production is sold at a premium price and the rest of the production is sold at the conventional price.

Overall, eight alternative channels were identified for vegetable marketing from our study and the main channel throught which products flow from farmers to consumers via different intermediaries were found in channel eight.

2.3.2.2. Marketing performances

To analyse the performance of the market, we calculated marketing margins. A marketing margin is defined by Mendoza (1995) as a measure of the share of the final selling price that is captured by a particular agent in the marketing chain. It includes costs and net benefits.

The calculation of the margin help to show the distribution of the added value throughout the various actors as vegetables move from production to collectors, wholesalers, retailers, and finally to consumers. The marketing margin is the price difference between final consumers and the farm gate price (Ghorbani, 2008). When market margins are high, this means that intermediaries support high costs or obtain higher profits.

According to Mendoza (1995), the computation of the Total Gross Marketing Margin (TGMM) is related to the final price paid by the end buyer and is expressed as a percentage. Thus, the following equation is used to calculate the TGMM.

$$TGMM = \frac{Consumer\ price - Producer\ price}{Consumer\ price} * 100 \quad (1)$$

Where, TGMM= Total Gross Market Margin

$$GMM_i = \frac{SPi - PPi}{TGMM} * 100 \quad (2)$$

$$MGM = consumer's price - producer's price \quad (3)$$

Where:

MGM= Marketing gross margin

GMM_i = Marketing margin at stage i;

SPi= selling price;

PPi= purchasing prise

The producer's share (PS) which is the ratio of producers' price to consumers' price is calculated as follow.

$$Pdshare = \frac{Producer\ price}{Consumer\ price} = 1 - \frac{Marketing\ margin}{Consumer\ price} \quad (4)$$

Where: Pdshare = Producer share

A summary of our survey result is given on the table 3.4 below.

Table 2.5: Average marketing prices (Prices in FCFA per kg)

	Producer			Wholesaler			Retailer		
	Cabbage			Eggplant			Green Pepper		
	Cold season	Dry season	Rainy season	Cold season	Dry season	Rainy season	Cold season	Dry season	Rainy season
Producer Selling Price in CFA	100	150	250	75	109	200	200	300	700
Wholesaler purchasing price in CFA	100	150	250	75	109	200	200	300	700
Wholesaler selling price in CFA	267	285	450	109	130	272	400	600	1000
Retailer purchasing price in CFA	267	285	450	109	130	272	400	600	1000
Retailer selling price in CFA	350	400	600	300	400	700	700	900	1500

Source: Survey result

The table 2.5 above shows that vegetable prices vary according to the season. There is a similar pattern for producer, wholesaler and retailer from one season to another. All market agencies receive high prices during the rainy season because pest attacks reduce the production and supply becomes smaller than demand. Finally, along the chain, the retailers are receiving the highest prices. In addition, followed by the wholesaler and then the producers. In addition, traders support some costs related to transport, load and unload of the products, store costs and minucipal taxes. Vegetables are transported from the rural comunities to Dakar main wholesale markets (Thiaroye, Pikine and Castor) mostly by brokers called “Bana-Bana” through vehicles. Then from wholesale markets vegetables are transported to different small retail markets of Dakar through common vehicle system called “clando” or by taxi and to some cases by human power called “pouss-pouss”.

Due to the reason that respondents were not able to recall correctly those costs and time constraint, we were not able to deeply analyse the chain.

Table 2.6: Marketing margin analysis

	Producer			Wholesaler			Retailer		
	Cabbage			Eggplant			Green Pepper		
	Cold season	Dry season	Rainy	Cold season	Dry season	Rainy	Cold season	Dry season	Rainy
Producer Selling Price in CFA	100	150	250	75	109	200	200	300	700
Wholesaler purchasing price in CFA	100	150	250	75	109	200	200	300	700
Wholesaler selling price in CFA	267	285	450	109	130	272	400	600	1000
Retailer purchasing price in CFA	267	285	450	109	130	272	400	600	1000
Retailer selling price in CFA	350	400	600	300	400	700	700	900	1500
TGMM	0.71	0.625	0.58	0.75	0.73	0.71	0.71	0.67	0.53
GMM	250	250	350	225	291	500	500	600	800
GMMp	0.29	0.375	0.42	0.25	0.27	0.29	0.29	0.33	0.47
GMMw	0.67	0.54	0.57	0.15	0.07	0.14	0.4	0.50	0.38
GMMr	0.33	0.46	0.43	0.85	0.93	0.86	0.6	0.50	0.63
Pdshare	0.29	0.38	0.42	0.25	0.27	0.29	0.29	0.33	0.47

Source: survey data, 2014-2015

Total Gross Marketing Margin are high for all crops during all seasons, this means that there were many intermediaries involved in the marketing of vegetables along the chain. Table 3.5 also reveals that during the cold season, 71%, 75%, and 71% total marketing margin were respectively added to cabbage, eggplant, and green pepper prices when they reach the final consumers. Producers get the highest share for each crop considered during the rainy season, 42% for cabbage, 29% for eggplant and 47% for green pepper. High TGMM diminishes the producer's share. Traders are taking above 50% of the total profit margin while producers who are bearing a large share of the risk, takes less than 50% of the profit margin. These findings imply that there is a disproportion in the share of benefits and that this is a reflexion of poor relationship among actors.

The marketing margins obtained for each marketing agent show that there is a larger difference in the consumer's price spread along the marketing chain. The marketing margin of each actor varies from one season to another for different crop types. Wider marketing margin according to Cramer and Jenson (1982) indicates high price to consumers and low price to producers and it is an indicator of the existence of market imperfection. From the table 3.5 above, it is clear that the marketing margins taken by retailers are larger compared to those taken by producer or wholesalers. This can be the result of the existence of market inefficiencies but also it can be due to high real marketing cost or a very big producer and consumer price difference.

2.3.3. Challenges and constraints for production and marketing of vegetables

2.3.3.1. Production aspect

There are many development challenges influencing vegetable production in the Niayes region. The respondents have identified a number of challenges that affect production and productivity. They include:

-Lack of financial means due to non accessibility to credit

-Absence of storage facilities

-Poor materials and post-harvest techniques

-Overutilization of chemicals which caused health damage and pollution

-Lack of market information

-Land degradation due to erosion , low fertilization and salinization

-lack and cost of improved seeds

3.3.3.2. Marketing aspect

The perishable nature of vegetable products is one common problem that leads to product loss if not marketed. High percentage of loss is recorded during the cold season due to low price and high supply. Vegetable producers usually don’t manage well the planting and harvesting periods so as to not send their production at the same time at the market place. When the same vegetable crops are harvested and send to the market at the same period, supply exceeds demand and prices collapse. When all the production is not marketed, some vegetables get spoiled due to the absence of proper storage facilities in the markets. Price volatility is another common issue.

Producers are usually uncertain about retail prices. They mostly have to deal with brokers (“Bana-Bana”) who usually use price setting practices that do not benefit small farmers. Another key challenge identified is the high cost of seed which increase production costs.

Conclusion of the chapter:

This chapter has first given a general overview of horticulture production in Senegal and in particular in the Niaye zone. It is found that the horticultural industry is steadily increasing despite the difficulties that prevent the government and policy makers to reach their stated goals. Finaly, this chapter has analyzed the production system and the distribution pathways of irrigated vegetables within two farming systems. The medium-sized farm which is the family style is dominant in the region. In addition, an analysis of marketing channels in both systems has shown that there are many people involved in the marketing of vegetables and this does not profit to farmers and consumers

Chapter 3: Review of Literature

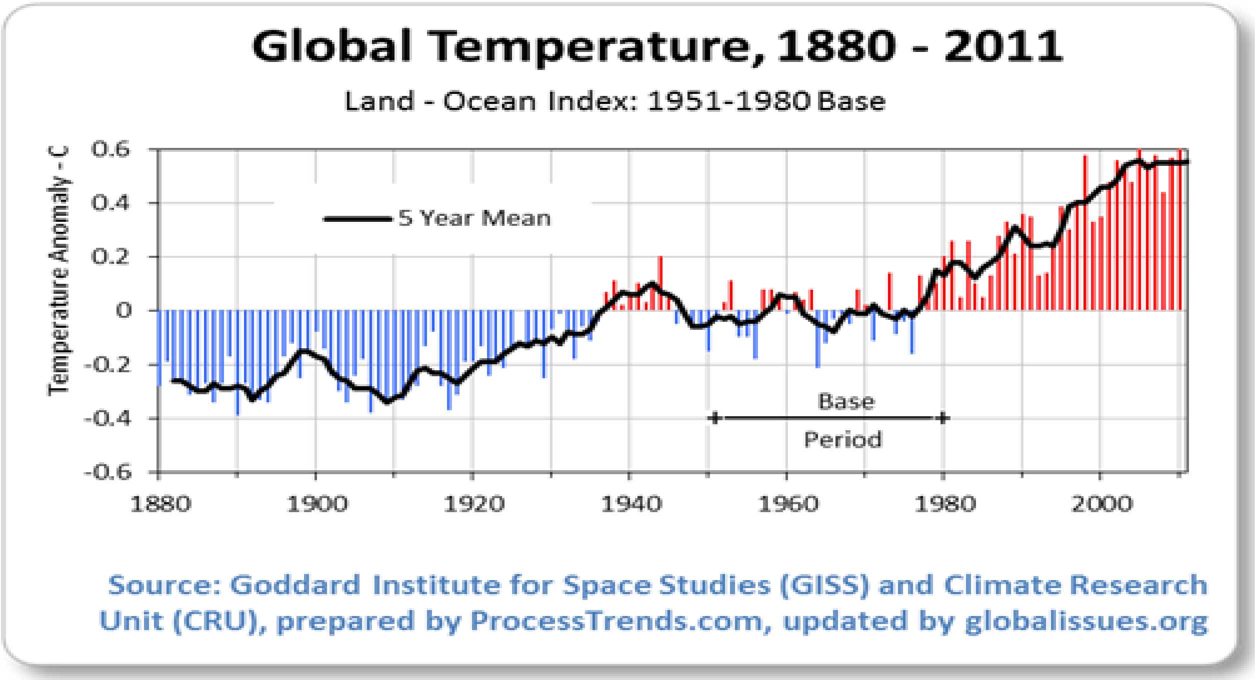
This chapter consists of three major sections. Section one concentrates on the conceptual and theoretical review. Section two presents a review of empirical studies related to the technological adoption agriculture in developing countries on one hand and on the other hand a review of empirical Studies attempting to document on the economic and environmental performances of organic farming. The last section makes a summary of the chapter.

3.1. Conceptual and Theoretical Review

3.1.1. Climate change

Climate change is one of the most serious threats that the world faces today. The planet has been characterized by frequent changes in its climate but climate changes people talk about today seem to be different. Today, climate change is a global phenomenon that is impacting on people's lives in different ways and to varying degrees. Human activities have led to a rapid and unprecedented increase in Greenhouse gas (GHG) emissions in the atmosphere and it is now considered 'unequivocal' that the global climate is changing. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014). During the 20^{th} century, the average global temperature increased by 0.6 ◦C (IPCC, 2001 and 2007). This temperature increase is likely to have been the largest of any century during the past. The graph below shows this evidence. From the figure we can see that the temperature anomaly started to be consistently positive since 1980. Rapid industrialization and population growth started from that period. This increase in the temperature is gradually warming the planet and having a number of knock-on effects in terms of changing rainfall patterns, rising sea levels, and more unpredictable weather events (Clement et al., 2011). According to climatologists, there is a high correlation between increases in global temperature and increases in carbon dioxide and other greenhouse gas concentration during the era from, 1980 to present and they agree that the causes is human activity, predominantly the burning of fossil fuels (Schneider and Lane, 2004). Fossil fuels are energy sources such as coal, petroleum and natural gas. Deforestation and other land use changes and industrial and agricultural activities like cement production and animal husbandry also contribute to a lesser extent than burning of fossil fuels to greenhouse emissions.

Figure 3.1: Global trend of temperature increase from 1880 to 2010



Source:http://www.globalissues.org/article/233/climate-change-and-global-warming-introduction

There is a growing consensus amongst scientists that the cause of the temperature rise during the last decades is the result of an increase in carbon dioxide in the atmosphere due to human activities. However, climate change is not only about increase in temperature but also about variations in precipitation, extreme weather events such as drought or flood and inter-annual variability of phenomena like El Nińo/ Southern Oscillation and North Atlantic Oscillation (NAO). Global land precipitation has increased by about 2 percent over the 20th century (Hulme et al., 1998). But note that this increase is not spatially and temporally uniform. While there have been increase in precipitation in some part of the globe like in North America and Western Russia, there have been decrease in precipitation in others such as in the northern Sub-tropic and the equatorial regions (Salinger, 2005). The scientists find out that recent climate change is mostly due to human activities from an understanding of basic physics, but also by comparing observations with models, and fingerprinting the detailed patterns of climate change caused by different human and natural influences (IPCC, 2013).

Climate change in the International Panel on Climate Change (IPCC) usages refers to as "any change in climate over time whether due to natural variability or as a result of human activity". In contrast, the United Nations Framework Convention on Climate Change (UNFCCC) in its Article 1, defines climate change as the change that can be attributed "directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period".[3] Compare to the IPCC, the UNFCCC makes a distinction between climate change attributable to activities altering the atmospheric composition, and climate variability attributable to natural causes. On the other hand, climate change has been used interchangeably with the term "global warming". There is however, a distinction between the two. Global warming refers to the phenomenon of increasing average surface temperatures of the Earth over the past one to two centuries and is a concept related to the more general phenomenon of climate change (Mann M.E., 2009). So, while global warming refers to an increase in global temperature, climate change refers to changes in the totality of attributes that define climate (temperatures, precipitation patterns, winds, ocean currents, and other measures of the Earth's climate).

In recent decades, climate change has impacted on natural and human systems on all continents and across the oceans (IPCC WGII, 2014). During 2010, many regions of the world experienced severe weather related event such as flash floods and widespread flooding in large part of Asia and parts of central Europe, but also heatwave and drought in Russia and China and severe drought in Sub-Saharan Africa (UNFCCC-Fact sheet, 2011). Today, there is growing public acceptance of human-induced climate change. Most people believe that climate change is induced by human activities through fossil fuel burning, clearing forests and other practices that increase the concentration of greenhouse gases (GHG)[4] in the atmosphere (ISDR-Briefing note 1, 2008). Further, the fifth Intergovernmental Panel on Climate Change (IPCC) report states that: "it is extremely likely (95 percent confidence) more than half of the observe increase in global average temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcing together". Comparing this statement to the 2007 IPCC statement which stated that: "most of the observed increase in global average temperature since the mid-20th century is very likely (90 percent confidence) due to the observed

[3] http://unfccc.int/essential_background/convention/background/items/1349.php
[4] Greenhouse Gases (GHG) are

increase in anthropogenic greenhouse gas concentrations”, evidence about man-made climate change is becoming clearer. Potential adverse impacts of climate change according to IPCC fourth assessment report include sea-level rise, increase frequency and intensity of wider-fires, floods, droughts, and tropical storms, changes in the amount, timing and distribution of rain, snow and runoff, and disturbance of coastal marine and other ecosystems. Scientific community, stakeholders, government and international organizations are making effort toward finding ways to tackle climate change through adaptation and mitigation.

3.1.2. Sustainable Intensification

Food security is said to be one of this century’s key global challenges (The Royal Society, 2009). Further, the rapid increase of the population, food demand and climate change could lead to a global crisis in the coming decades unless action is taken now. Therefore, it is now universally admitted that there is a need to take into account sustainability in agricultural resource management (Blanco-Fonseca M., Flichman G., and Belhouchette H., 2011). Sustainability is a concept that has been applied to a vast array of situations such as the conditions for success of a World Bank agricultural development project to the problem of creating conditions for the improvement of the situation of the whole human race in the “further future” (Kneese and Kopp, 1988). Thus, sustainability is a relative term and an appropriate criterion for sustainability will depend very much upon the context (Prezzy John, 1992). There have been a variety of definitions of sustainability during the last decades. Early definitions include those of:

Coomer (1979): “the sustainable society is one that lives within the self-perpetuation limits of its environment. That society… is not a ‘no-growth’ society….It is, rather a society that recognizes the limits of growth… and looks for alternative ways of growing.”

Tietenberg (1984): “the sustainability criterion suggests that, at a minimum, future generations should be left no worse off than current generations.”

Pearce et al. (1990) define sustainability from an economic point of view as an improvement of the performance of a system so as to not exhaust the basic natural resources on which its future performance depends. In this definition, it is emphasized the importance of preserving the natural resources base.

A commonly use definition of sustainability is implied in the following definition of sustainable development which is found in the WCED-Brundtland Report (1987): "Sustainable development is development that meets the needs of the present without compromising the ability of the future generation to meet their own needs." On the other hand, the term intensification in agriculture has been defined by Tiffen et al. (1994) as: "increased average inputs of labor or capital on a smallholding, either cultivated land alone, or cultivated and grazing land, for the purpose of increasing the value of output per hectare". While the Green Revolution enabled massive increase in yields and the achievement of self-sufficiency in grain many Asian countries, it had a very uneven effect in African countries and its negative environmental impacts have been a cause of concern.

The term sustainable agriculture intensification dates back to the 1990s and was coined in the context of African agriculture, where often yields are low and environmental degradation a major concern (Garnett T and Godfray C, 2012). According to Reardon et al. (1999), sustainable agriculture intensification is defined following two criteria: (i) an environmental criterion where technology protects or enhances the farm resource base by maintaining and improving land productivity; and (ii) an economic criterion that ensure that the technology meets the farmers' goals and is profitable. By definition, sustainable agriculture systems are said to be less vulnerable to shocks and stress (J. Pretty et al. 2011). Further, sustainable agriculture intensification contributes to increasing systems' resilience which is a critical factor in light of climate change. Sustainable agricultural intensification could be achieved through multi-technology adoption. According to the FAO guide to the sustainable intensification of smallholder crop production in 2011, sustainable intensification is built on the following components:

Farming systems: farmers can produce better and save natural resources as well time and money by practicing conservation agriculture which minimizes tillage, protect the soil surface, and sows crop in rotations that enrich the soil.

Water management: sustainable intensification requires smarter, precision technologies for irrigation and farming practices that use ecosystem approaches to conserve water.

Soil health: the best yields are achieved when nutrients come from a mix of mineral and natural sources. Policies that promote soil health should hence encourage conservation agriculture and mixed crop-livestock and agro-forestry systems that enhance soil fertility.

Plant protection: integrated pest management can be achieved through farmer field school, local production of bio-control agents, strict pesticides regulations, and removal of subsidies on pesticides.

Policies and institutions: in order to encourage smallholders to adopt sustainable crop production intensification, fundamental changes are needed in agricultural development policies and institutions. Overall, farming must be profitable and affordable to smallholders.

In a report by Garnett and Godfray (2012), many concepts related to sustainable intensification have been distinguished. They are:

Ecological Intensification: it is a concept which is essentially synonymous with an environmentally oriented interpretation of sustainable intensification. This concept was coined in a paper by Cassman (1999).

Agroecology: this concept of sustainable intensification is based on enhancing the habitat both above ground and in the soil to produce strong and healthy plants by promoting beneficial organisms while adversely affecting crop pests (weeds, insects, diseases, and nematodes).

Permaculture: it is a movement that incorporates many ideas from agroecology but very specifically advocates certain design principles derived from observations of natural ecosystems in order to create sustainable settlements and agriculture. The movement was much influenced by the writing of Bill Mollison (1988).

Organic agriculture: it is a production system that sustains the health of soils, ecosystems and people. It is a specific type of food production that combines tradition, innovation and science that emphasizes the sustainability of the local agro-environment and reductions in the use of synthetic inputs.

Ecofunctional intensification: this concept is promoted by the organic movement and its goal is a more efficient use of natural resources and processes, improved nutrient recycling, and innovative agro-ecological methods for enhancing the diversity and the health of soils, crops and livestock. It is characterized by a synergy between different component agro-ecosystems and food systems.

Climate smart agriculture: it is a term that was coined by FAO which defined it as “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals.

Eco-efficiency: this concept appeared first as a proposal from the World Business Council for Sustainable Development (WBCSD) which defined it as means producing “competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the earth’s estimated carrying capacity”.

Technological optimism: in contemporary agriculture thinking, technological innovations are seen as making major contribution to producing more food with less environmental impact.

Overall, these are the major terms in use to capture the goal that sits at the heart of sustainable intensification. According to The Montpelier Panel (2013) sustainable intensification is an ambitious objective but is achievable if we focus on being:

Prudent, in the use of input, particularly those which are scare, are expensive and/or encourage natural resource degradation and environmental problems;

Efficient, in seeking returns and in reducing waste and unnecessary use of scare inorganic and natural inputs;

Resilient, to future shocks and stresses that may threaten natural farming systems;

Equitable, in that the inputs and outputs of intensification are accessible and affordable amongst beneficiaries at the household, village, regional or national level to ensure the potential to sustainably intensify is an opportunity for all.

3.2.2. Link between Climate Change and Sustainable Intensification

Sustainable intensification can play an important role in enhancing agriculture production while restoring degraded lands, mitigating global warming by sequestering atmospheric CO2 in soils and vegetations, adapting to climate change by using recommended practices[5]. Sustainable intensification is an essential means of adapting to climate change, also resulting in lower emission per unit of output (Campbell et al., 2014). The extent to which agriculture is threatened by expected climate change is now beyond debate, and most climate scientists are not optimistic about the potential to reverse course (IPCC, 2007). In addition, even if carbon dioxide production were to cease completely today, the climate will continue to change for many years to come. So, adaptation is necessary to avoid or reduce the negative impacts and to explore any potential benefits of climate change (CEPS, 2008). There are various means through which adaptation and mitigation to climate change could be achieved such as enhancing soil quality; filtering and moderating the hydrological cycle; improving soil biodiversity; regulating the carbon, oxygen and plant nutrient cycles; enhancing resilience to drought and flood; and carbon sequestration (Campbell et al., 2014). All these can be founded in the different components of sustainable intensification. For example, a set of soil-crop-nutrient-water-landscape system management practices named conservation agriculture (CA) has the potential for managing decreasing soil productivity and for improving the resource-use efficiency and the natural resources based (Pisante et al., 2012). Hence, CA which is a form of sustainable intensification adapts and mitigates climate change. The followings are others examples of component of sustainable intensification that adapt and/or mitigate climate change:

Climate Smart Agriculture (CSA) is defined as “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes Greenhouse Gases (GHGs) (mitigation), and enhances achievement of national food security and development goals” (FAO, 2010). From this definition we can see that CSA is a farming system that aims at promoting the adoption of sustainable agriculture practices that at the same time reduce GHG emissions, whilst improving the efficiency and resilience of rural communities and agricultural activities. Some countries where CSA is the major aim in agricultural policies and national strategies are Brazil with their Low Carbon Agricultural Program, Australia with the Carbon Farming Initiative, Denmark with

[5] http://www.springer.com/environment/soil+science/book/978-3-319-09359-8

the Agreement for Green Growth, and Kenya with the Agricultural Carbon Project (Cooper et al., 2013).

The System of Rice Intensification (SRI) is an evolving set of practices, principles, and philosophies aimed at increasing the productivity of irrigated rice by changing the management of plants, soils, water and nutrients.[6] The SRI can reduce water requirements, increase land productivity and promote less resilience on artificial fertilizers by applying organic matter to the soil. SRI can mitigate and adapt climate change because of its method, plants are strong and healthy and more resilient to pest, diseases and extreme weather conditions. SRI has been adopted worldwide, including the Senegal. Validation of the benefits of SRI has been reported from more than 50 countries of Asia, Africa, and Latin America (Selvaraju, 2013). Rice production is said to be a key emitter of greenhouse gases, but with the SRI CH_4 emissions are reduced by avoiding the need to flood rice fields, and GHG emissions are also decreased because nitrogen fertilizers are not required (IFOAM, 2009).

Organic farming has many definitions, but the one that retain our attention in the literature is the one provided by Lampkin and Padel (1994). They state that the aim of organic farming is:" to create integrated, human and environmentally and economically sustainable agricultural production systems, which maximize resilience on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable levels of crop, livestock and human nutrition, protection from pests and diseases, and an appropriate return to human and other resources employed". The Food and Agriculture Organization of the United Nations (FAO) Sees organic farming as an effective strategy for mitigating climate change and building robust soils that are better adapted to extreme weather conditions associated with climate change (Niggli et al., 2009). Organic farming is by its nature an adaptation strategy that can be targeted at improving the livelihoods of rural populations and those parts of societies that are especially vulnerable to the adverse effects of climate change and variability such as the rural population in Sub-Saharan Africa (Muller, 2009). Burdick (1992) further emphasize that organic agriculture not only enables ecosystems to better adjust to the effects of climate but also offers a major potential to reduce the emissions of agricultural greenhouse gases. Thus, organic farming not only adapts climate change but also mitigates it and

[6] IRRI's Definition of SRI (http://irri.org/news/hot-topics/system-of-rice-intensification-sri)

therefore may contribute partly to accomplish the carbon sink idea of the Kyoto Protocol. A study by FAO (2002) highlighted the benefits of organic agriculture on environmental goods and services. Regarding soils, the organically-farmed soils have significantly higher biological activity and higher total mass of micro organisms, making for more rapid nutrients recycle and improved soil structure. Water pollution due to Nitrate leaching is significantly lower in organic agriculture compared to conventional systems. So, organic agriculture poses no risk of ground and surface water through synthetic pesticides. Organic agriculture is beneficial to the air in that it recycles organic matter, tightens internal nutrient cycle, and contributes to carbon sequestration. Energy consumption in organic agriculture is more efficient than in the conventional systems. Biodiversity species such as insects and micro-organisms have been shown to increase when land is farmed organically. In addition organic agriculture offers ecological services by providing vast food resources and shelter for arthropods and birds, and contributes to the conservation of and survival of pollinators. Last but not least, organic agriculture systems create a diversity of landscapes, which contribute to functional diversity and aesthetical values.

Sustainable agricultural intensification has been developed in Africa since 1990s (Pretty J. et al. 2011). Senegal is no exception to this because many projects and programs related to crop improvements, agro-forestry and soil conservation, conservation agriculture, integrated pest management, horticulture, organic farming, Systems of Rice Intensification, etc., have been recorded and recognized to have beneficial effects.

Organic agriculture has been promoted in Senegal since 1986 by an NGO named END-PRONAT. In fact, modern agriculture has gradually replaced traditional agriculture by developing a production for marketing. It intensifies the production by the increase use of fertilizers and pesticides that enable the increment of yields in the short term. But the intensification of agriculture associated with population growth and unstable climate conditions (chronic deficit rainfall) reversed the gains of farmers. It is noticeable in many different areas of Senegal the degradation of natural resources with repercussions on all rural activities (production, processing, small crafts). Further, agricultural policies are most often defined without the involvement of actors and without long-term vision that promote the management of climate change. This situation has pushed producers and families of small farmers in a precarious situation that limit their potential for innovation and to improve income from production. This context led ENDA PRONAT to implement programs to stimulate change towards a healthy and sustainable agriculture, thereby increasing the profitability of agriculture through agro-ecological techniques and to better secure natural areas and biodiversity.[7] In doing an inventory of the existing projects related to sustainability and adaptation/mitigation to climate change that have been implemented in Senegal, we came across a high number of nationally-focused and regional projects that simultaneously promote sustainability and adaptation and/or mitigation to climate change.

3.2. Theoretical Review:

3.2.1. Approaches to assess the effects of Agricultural Technology Adoption and Diffusion

Several approaches have been developed to investigate adoption and diffusion of agricultural innovations. Some are more oriented on demonstrating the positive results of the innovations and the well-done work of its developers and diffusers (Horton et al., 1993; Airaghi et al., 1999) and others were more suited and applied to adoption decisions. At the beginning, impact assessment of technology adoption focused on the social aspects (improving food security, improving nutrition, reduction of poverty, improving knowledge on an innovation, creation and change in social network, etc.) and economic aspects (generation of employment, increasing income, reduction of costs, increasing benefits, improving prices, increasing participation in the market, etc.), but in 1990s the environmental aspects (soil erosion and degradation, effects on biodiversity, change in hydrological cycles, effects of climate change, etc.) also started to gain importance (Barrientos-Fuentes and Berg, 2013).

Impact assessments are divided into two categories:

-ex post studies that assess technologies already used, and

-ex ante studies that assess technologies not yet adopted

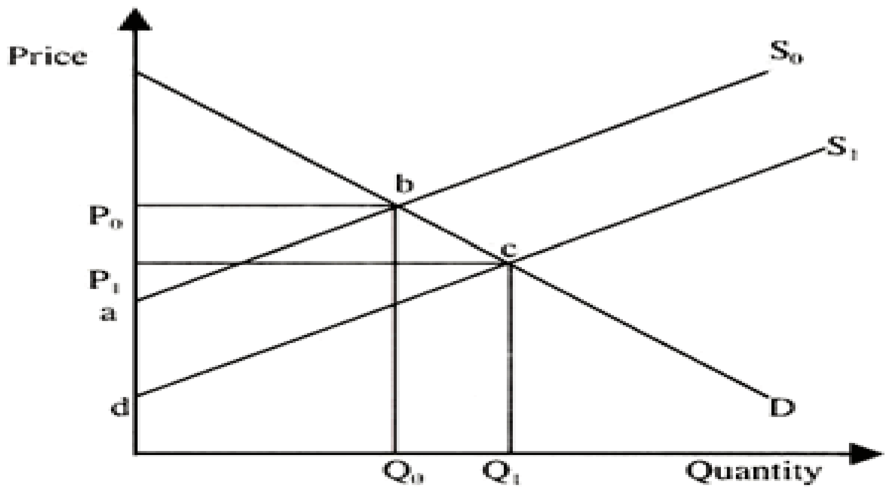
From the literature, we have identifies the following four main groups of methods used to do impact assessment of technology adoption.

[7] Source: ENDA-PRONAT-in capitalization of Enda-Pronat.

The Economic Surplus method

the economic surplus method is commonly used to assess the impact and distribution effects of a technology or a research activity by using a partial equilibrium approach to estimate the net benefits, the internal rates of returns and the distribution of such gains to producers and consumers expressed as changes in producer and consumer surplus (Manyong et al., 2006). Assessment using the economic surplus method provides a relatively simple and flexible approach to analyze the adoption of new technologies by allowing for the comparison of the results of situations with and without the use of new technology (Mensah and Wohlgenant, 2014). Thus, the economic surplus methods help to estimate the economic benefits generated by the adoption of new technologies, compared to the situation before the adoption. An extensive examination on the use of economic surplus models for assessing agricultural research is found in the work of Alston et al. (1995). They can be use for both ex-ante (when technologies are not currently adopted and the study predicts the impact of research in the future) and ex-post studies (assessment of the impact of technologies already adopted). The economic surplus method puts a monetary value on the increased supply and reduced production costs. Consumer gain a surplus from buying their bundle of good at a lower price and producer also gain a surplus from selling greater quantities in the market and by reducing production cost (Alene et al., 2013). Economic Surplus has two components: the consumers' surplus which is the difference between the benefits and costs of consumption and the producers' surplus which is the difference between returns and costs of production (Vere et al., 2005). The theory of economic surplus gives three propositions as a welfare measure: the first one is that demand price for a commodity represents its unit value to consumers, the second is that the supply price represents its unit value to producers, and the third one is that welfare changes are additive across the economy irrespective of to whom they accrue (Harberger, 1971). Norton et al. (1995) show that, when widespread adoption of new technology occurs across large areas, change in crop prices, cropping patterns, producer profits, and social welfare can occur. These changes can be justified by the fact that cost differs and supplies may increase affecting prices for producers and consumers. The basic of the model is explained in the figure below.

Figure 3.2: Economic Surplus Model



The demand for the commodity is denoted D, whereas the supply curve before technology adoption is S_0 and the supply curve following technological change is S_1. The equilibrium before adoption of technology is (P_0 , Q_0), while the equilibrium post-adoption or research is (P_1, Q_1). The total benefit technological change supply shift is equal to the area beneath the demand curve and between the two supply curves (area= abce). The total benefit is equal to sum of benefits to consumers (area= P_0bcP_1) and the benefits to producers (area= $P_1 ce\ minus\ P_0 ba$. The economic supply method is a benefit cost approach that has the advantage of incorporating several criteria related to economic efficiency and distribution into one or two measures. This method is one of the suitable frameworks to measure the aggregated social benefits of a research project in agricultural research (Wander et al., 2004). However, this method can be difficult to apply to a larger number of commodities or research areas because data types necessary for the analysis do not exist for all commodities (Pal and Jha, 1997). Overall, the economic surplus method is used to assess the wide-level ex post aggregate impact of the adoption of new technology (the agricultural research) by measuring the combine effects of production and income.

Econometric Models

Econometric approaches use a production function, cost function, or a total factor productivity analysis to estimate the change in productivity due to investment in research (Maredia et al., 2002). According to Masters (1995), the econometric methods aim to estimate a marginal productivity of research during a long time period. The production function approach is used for assessing the impact of varietal technology on total factor productivity (Tesema, 2006). At farm level, the impact of technology adoption is assessed through a specified production function and is based mainly on factor productivity such as yield, labor and other input productivity associated with the use of the innovation (Sannino et al., 2004). Indicators commonly used to assess the impact of new technology include increased yields or reduced work load, high product quality and income. Nowadays, there is an extensive use of choice models including binary logit/probit in agricultural economics to study technology adoption, conservation reserve program and other agricultural policy questions (Zapata et al., 2007). Probit and logit approaches are probabilistic dichotomous choice quantitative models. They are statistically similar, except that the probit model assumes a normal cumulative distribution function while the logit model assumes a logistic distribution of the dependent variable (Amemiya, 1981). Studies using probit or logit models to assess technology adoption can be found in Amegbeto et al. (2002), Doss and Moriss (2001), Harpper et al. (1990) and Endamana et al. (2006). Logit and Probit models are mostly used to analyze factors affecting adoption decision. In all these methods, the dependent variable is constraint to lie between 0 and 1 and their advantage is that their assumptions are realistic for binary adoption study data.

Impact Evaluation Methods

Nowadays, impact evaluation is broadly recognized as a tool intended to determine whether a program had desired effects on individuals, households, and institutions and whether those effects are attributable to the program intervention. Further, it can also explore unintended consequences, whether positive or negative, on beneficiaries (Baker J.D., 2000). A major challenge in impact evaluation is the search for the counterfactual. The World Bank Group (2012) defines the counterfactual as an estimate of what the outcome (Y) would have been for a program participant in the absence of the program (X). Methods for establishing a valid counterfactual include experimental (randomization), and quasi-experimental approaches; there may also be opportunities to exploit ‘natural experiments’ (Prowse and Snilstveit, 2010). By randomly allocating the intervention among eligible beneficiaries, the assignment process itself creates comparable treatment and control groups that are statistically equivalent to one another, given appropriate sample sizes (Baker J.D., 2000). Overall, the randomization method consists of randomly assigning participants into the intervention and control groups. Quasi-experimental methods are those that use comparison groups rather than randomly-assigned control groups as the baseline or counter factual against which to measure net program impact. Estimation of the welfare gain of adoption of agricultural technologies based on non-experimental observations is not trivial because of the need of finding on counterfactual of intervention. The most frequently methods use in Quasi-experimental evaluations are: the propensity score matching methods, the double difference or difference-in-differences methods, the instrumental variables or statistical control methods, and the reflexive comparison methods.

Propensity Score Matching (PSM): it is the one that distinguish a group of individuals, households or firms with the same observable characteristic with those participating in the project. The identification is done by estimating a statistical model of the probability of participating (propensity to participate) using a regression model with participation as the zero-one dependent variable, and a set of observable characteristics, which must be unaffected by the intervention, as the explanatory variables. The coefficients are used to calculate a propensity score, and participants matched with non-participants based on having similar propensity scores. The project impact is determined by the difference in the mean outcome of the two groups. Propensity Score Matching can be very attractive but it face a problem named selection on unobservable as in all Quasi-experimental approaches.[8]

Difference-in-Differences (DD): compare with Propensity Score Matching, this method assume that unobservable heterogeneity in participation is present but that such factors are time invariant. This method relies on a comparison of participants and non-participants before and after the intervention in order to estimate the impact of the project. Therefore, the difference in effect is calculated between the observed mean outcomes for the treatment and control groups before and after program intervention. The DD method has the advantage to relax the assumption of conditional exogeneity on observed characteristics, but also it offers an intuitive way to take care of selection on unobservable characteristics. The main disadvantage of this method, however, deals with the assumption on the notion of time-invariant.[9]

Instrumental Variables method (IV): it is a method which requires using a variable (or instrument) that facilitates predict participation in the program but that is uncorrelated with unobservable characteristics that influence the outcomes of interest or affect such outcomes

[8] (White, 2006)
[9] Khandker et al., 2010

directly. The Instrumental Variable Method involves two steps in estimating the impact of an intervention through statistical econometric models. It first predicts program participation based on the instrumental variable. Then it calculates the program's impacts by drawing on the predicted value of the equation estimated in the first step. [10]

Reflexive Comparisons Method: it is the one in which a baseline survey of participants is conducted before the intervention and a follow-up survey is carried after. The baseline offers the comparison group, and the impact of the program is measured by the change in outcome indicators before and after the intervention.[11]

Quasi-experimental Designs is used as an alternative to constructing a counterfactual in impact evaluation of program interventions. While they offer many advantages especially in cases where experimental approaches are not applicable, there are some concerns with the use of Quasi-experimental approaches in impact evaluation. Nguyen and Bloom (2006) distinguished the following estimation biases when using non-experimental methods.

Omitted variables estimation bias: this type of bias arises when one fail to account for observable variables. One example where this can happen is when estimating the probability of program participation in a PSM, education which is one of the determinants of the program participation fails to be included.

Selection bias: this type of bias comes from endogenous program placement. Usually, some endogenous program placement such as poverty reduction programs makes program participant and nonparticipant different in roughly a set of characteristics. Further, even in the case of voluntary participation, that self-selection of participants into the program makes them different from non-participants. These make those who are not in the program not a good comparison for those who are in the program and therefore observe difference in the outcome of interest is attributable to both program and pre-existing differences between participants and non-participants.

Misspecification: this type of bias may arise when modeling the behavior of participants and non-participants.

[10] World Bank Group Impact Evaluations: Relevance and Effectiveness
[11] Baker J.L., 2000

Bio-economic models

Bio-economic models were first developed in the eighties by scientists to operationalize the concept of sustainability by adding environmental components to classic economic models (Barbier and Carpentier, 2000). Since then, many different bio-economic models have been constructed in different places around the world. A group of researchers in Australia at the University of Western Austria wrote some methodological articles on different aspects of bio-economic modeling (Pannell et al., 2000). At the same time, at different places in Europe Bio-economic Farm Models (BEFMs) were made at the Institute Agronomic de Monpelier (Boussemart et al., 1996; Louhichi et al., 1999; Flichman and Jacquet, 2003) and in Netherlands at Wageningen University (Wossink et al., 1992; Berentsen and Giesen, 1995; Pascini, 2003). In the United States, some implications were found in the work of researchers like Rotz et al. (1989), Apland (1993), Crissman et al. (1998), and Barbier and Bergeron (1999). In West Africa, Barbier (1996 and 1998) made the Burkina Bio-economic Village Model which is a model that employs a recursive and dynamic linear programming model together with a biological model of soil condition and plant growth, and also incorporates risk aversion in the economic optimization component. In other places of Africa, the Ginchi Bio-economic Model is found in the work of Okumu et al. (2000) and in Zambia, Holden (1993) made the Zambia Household Model that simulates household decision and impact for households with various resource endowment in both "traditional and "modern societies". Finally in Asia implications were also found in the work of Van-Noordwijk (1999) who developed a model named Crop-Down Fallow-Up Model (CDFU).

According to Flichman et al. (2011), a bio-economic model is generally known as a link between models from different disciplines to provide multi-scale and multi-disciplinary answers to a given problem. Bio-economic modeling is defined as: a quantitative methodology that adequately accounts for biophysical and socio-economic processes and combines knowledge in such a way that results are relevant to both social and biophysical sciences (Kruseman, 2000). So from this definition we can see that there is a synergy between biophysical and socio-economic sciences. Another more restricted definition by King et al. (1993, p.389) states that: "A bio-economic model is a mathematical representation of managed biological system. Bio-economic models describe biological processes and predict the effects of management decisions on those processes. They also evaluate the consequences of management strategies in terms of some economic performance measure”. This definition emphasizes more on the biophysical sciences and management decisions than interaction between socio-economic and physical sciences compared with the previous definition. Another definition states that: A Bio-economic model is a model that links mathematical programming model formulation of farmers’ resource management decisions, to biophysical models that describe production processes and the condition of natural resources (Barbier and Bergeron, 1999). In agriculture, a bio-economic model is defined as a model that links formulations describing farmers’ resource management decisions to formulations that illustrate current and alternative possibilities (in terms of required inputs) in order to achieve certain output and associated externalities (Janssen and Van Itersum, 2007). Bio-economic modeling of agricultural systems according to Weersink et al. (2002) is based on tree different approaches namely accounting, regression, and mathematical programming. Our focus in this study is bio-economic models of agricultural systems. Bio-economic models have been also applied to forest and fishery systems. The Faustmann-Pressler-Ohlin Model has dominated the bio-economic modeling of forests (Perman et al., 1999). The model consist of forest value growth equation with an objective to determine what optimal rotation age will maximize net present value (NPV) of timber production for a forest stand; given tree growth, timber price, and planting costs. In fishery systems, bio-economic models of fisheries typically represent changes in fish population by relatively simple biological growth functions. The economic objective of the model is to determine what fishing efforts maximize profits and the environmental conditions are normally incorporated as parameters in mechanistic population growth function, limiting the ability of these models to account for environmental changes (Knowler, 2002; in Kragt, 2012).

A bio-economic model is use to link biophysical components with economic components. These economic components can be an optimization framework, optimal control models, cellular automater or simple budgets (Barbier and Carpentier, 2000). According to Barbier and Carpentier (2000), most bio-economic models are optimization models (mathematical programming models) which maximize or minimize an objective function under different constraints. Non optimization models tend to simulate processes without using optimization algorithm .Bio-economic models are usually applied at the farm level (Janssen and Ittersum, 2007) or at the household level (Holden and Shiferaw, 2004; Woelcke, 2006; Schönhart et al., 2011). Somme apply such models at the village, the watershed levels (Barbier, 1998; Okumu et al., 2000; Babier and Bergeron, 2001; Sankhayan and Hofstad, 2001; Okumu et al., 2002;; Nedumaran et al., 2013;), and at the national and regional levels (Stoorvogel, 1995; Kruseman and Bade, 1998; Bouman et al., 1999; Ruben et al., 2000; Louhichi et al., 2010). King et al. (1993) highlighted the design objectives for Bio-economic models which they apply to agricultural systems in the industrialized world. These major objectives are:

-Theory building: bio-economic models can contribute to theory building by establishing a common vocabulary for interdisciplinary work.

-Tool development: the systemic formal mathematical representation of the relationships of a problem permits solutions developed for one application to serve as a basis to confront challenges found in others. This is especially relevant for the biophysical processes involved.

-Technology and policy assessment.

-Decision Support: Models developed as decision-support systems can aid farm management decisions.

Bio-economic approaches consist of about four components (Ruben, Moll, and Kuyyenhoyen, 1998):

-*Mathematical programming models* that expose the resource allocation implications of alternative crop and technology choices and appraise the response of the farm household to policy interventions;

-*Agro-ecological simulation models* that describe how different land use practices affect yields and the condition of natural resources;

-*Farm household models* that assign the underlying relations regarding farm household decision making;

-*Aggregation procedures* that address the effectiveness of policy interventions for sustainable land use and well-being of farmers at regional level.

Bio-economic models are used to improve understanding of complex production systems, to assess the effects of policies and new technologies, and to support farm-level decisions (King et al., 1993). The bio-economic modeling approaches provide an appropriate framework for the analysis of the agricultural sector under climate change and land use changes. However, there are challenges to overcome using these models. These challenges are related to the lack of truly generic ready to-use-biophysical simulation models, insufficient procedures for model communication, and limitations of publicly available data (Mouratiatou et al., 2011).

To achieve each of the objectives of our study, a specific component of the bio-economic modeling will be used.

3.3. Empirical Review

3.3.1. Review of Empirical Studies on the assessment of Agricultural Technology Adoption in Developing countries

The farm household modeling approach (Singh et al., 1986) has been extensively used to model decision making behavior of farmers to assess the effects of policy measures on land use decision and farmers' welfare. Early studies include those of Barlow et al (1983); Kruseman and Bade, (1998); White et al., (2005); Dolisca et al., (2008).

Since, numerous studies highlighted the benefits and attractiveness of the adoption of improved agricultural production technologies on the welfare of smallholder farmers in the developing world. In the Philippines, Laborte et al. (2009) used a farm household modeling approach to assess the possible technology adoption behavior of farmers in Ilocos Norte Province. Four alternative technologies were evaluated: Hybrid rice production, balanced fertilization strategy, site-specific nutrient management and integrated pest management. Their results reveal that all four alternatives considered are attractive to farmers, although simulations show differential adoption rate for poor, average and better-off households. They also found that in all technology simulations, relative profitability and risk, labor and capital requirement and availabilities are decisive factor in the adoption of alternative technologies. Finally, their conclusion drawn from policy simulation reveals that availability of low-cost credit led to the largest improvement in farmer welfare for poor and average households, but its effect on simulated adoption of alternative technologies was variable.

Tchale H. and Wobst P. (2005) use a non-linear household bio-economic model, which incorporates risk aversion behavior through a Target Minimization of Total Absolute Deviations

(MOTAD) approach to analyze the extent to which soil fertility management technologies developed by researchers in Malawi over the last decades is effective in increasing maize productivity and reducing food insecurity among farmers in the maize-based farming systems. Their results indicate that the soil fertility management technologies have improved farmers' yields but there were a wide disparity between actual farmers' yields and those obtained in on-farm research. The disparity is due to resource constraints which influence the choice of soil fertility management practices. Their study also found remarkable role of risk aversion in farmers' soil fertility management decisions.

Kassie (2011) used a bio-economic linear programming model to assess both the economic and the soil conservation implications of introducing legume-cereal intercropping in the mixed farming systems of the North-Western Ethiopian Highlands. The model combines household surveys with experimental data to investigate the benefits of forage legume-cereal intercropping in mixed farming system. The empirical results show that introducing forage legume-cereal intercropping into a traditional mixed farming model increases farm household income (a range of increase of 52-75 percent) and resource productivity (a range of increase of 10-14) percent, and reduces soil erosion (a range of decrease of 8-9 percent) and pressure on grazing land (a decrease of 65 percent). The study conclude that development interventions realizing the economic and environmental potential of forage legumes will help achieve a double goal of enhancing the livelihoods of rural households and at the same time preventing land degradation.

Recently, a study by Maruod E. Maruod et al. (2013) use a linear programming model to investigate the impact of improved seeds on smallholder productivity in Sudan. They found that improved seeds productivity trend compared to local were increased in all varieties. Further, their analysis of the marginal rate of returns shows that farmer can benefit from investment in improved seed. They conclude that the adoption of improved seeds is attractive to small farmers in Umrawaba locality and North Kordofan of Sudan and therefore they are advised to use improved seeds versus their own seeds to rose productivity and maximize the returns.

Another recent study is the one of Nedumaran et al. (2013) that assesses the ex-ante impact of key technological and policy interventions on the socioeconomic wellbeing of rural households and the natural resource base in a Watershed community in the Semi-Arid Tropic (SAT) of India. They develop a watershed level bio-economic model to assess the effects of watershed development programs promoted by the Indian government. Their model is based on three components: (i) a mathematical programming model that reflects the farm household decision-making process under certain constraints, (ii) an estimation of crop yield response to soil depth, and (iii) nutrient balances as indicator of sustainability. The assessment is based on productivity enhancing technologies of dry-land crops and increase in irrigable area through water conservation technologies. Their results indicate that productivity enhancing technologies of dry-land crops increase household incomes and also give incentives for conserving soil moisture and fertility. They conclude that the introduction of high yielding varieties and cereal-legume intercropping systems as component of the integrated watershed programs can indeed help improve the welfare of smallholder farmers by increasing their incomes and also enhancing the sustainability of the natural resources up on which their livelihoods depend. In addition, they suggest that it also stimulates sustainable intensification of crop production in the Semi-arid villages by controlling soil erosion and nutrient mining through investment in soil and water conservation and adoption of better land use patterns at the landscape level.

Despite the presence of some case studies of a bio-economic analysis of the impact agricultural technology adoption on the welfare of farmers in developing countries, there still a lack of empirical evidence based on bio-economic modeling of the impact of technology adoption on farmer wellbeing specially in Sub-Saharan Africa. This could be due to lack of appropriate analytical tools and because of methodological challenges. This study will contribute to the literature by using a mathematical programming model to assess the effectiveness of organic farming methods in the Niayes region of Senegal.

3.3.2. Review of Empirical Studies attempting to document on the economic and environmental performances of organic farming

Mitigation options that can contribute to food security, poverty reduction and resilience of agro-ecosystems are very important to sustainable development in developing countries as emissions from agriculture in those countries are more important. Several studies have attempted to document on the environmental and economic attractiveness of organic farming.

In Germany, a study by Zeddies (2002; in Goh, 2011) show that farms in southern Germany gave 50 percent lower N_2O emissions with the non-use of mineral N fertilizer inputs and also with the use of minimum inputs of animal feed from outside the farm.

Petersen *et al*. (2005) determined and discussed the aggregate greenhouse gas emission ($CO_2, CH_4, and\ N_2O$) from two different farming systems in southern Germany. They considered two representative farms: a farm A of 30.4 hectare fields that basically applied fertilizer at the rate of 188 kg N per hectare, and a farm B of 31.3 hectare fields that utilize neither synthetic fertilizers nor pesticides (organic farming system). The integrated assessment of greenhouse gas emissions included those from farm fields, pastures, cattle; cattle waste management, fertilizer production, and consumption of fossil fuel. Their results reported lower N_2O emissions from organic than conventional farms. In contrast a study by Flessa *et al*. (2002) in five European countries reported decreased N_2O emission rates in organic farms only when yield-related emissions were not considered.

Studies by Reganold *et al*.(1987) and Goh (2004) showed that a farming system based on organic farming is more effective in reducing soil erosion, in enhancing carbon sequestration, and in increasing and maintaining soil productivity. Similarly, many others studies based on long-term field trials have also shown the organic farming system compared to the conventional farming system is more effective in increasing soil organic carbon and soil productivity (Powlson *et al*., 1998; Nyamangara *et al*., 2001; LaSall et al., 2008; and Sainju et al., 2008). Under the permanent application of many components of organic cropping systems such as organic manures, plant residues, mixed cropping, legume-based pastures in crop rotation or agro-forestry, higher organic carbon accumulation was obtained (Drinkwater *et al*., 1998; Kumar & Goh, 2000; Goh, 2001; 2002).

Another study by Teasdale *et al*. (2007) analyzed a comparison of a nine-year field trial of organic corn production that uses tillage system, with selected conventional tillage systems. Their results revealed that in spite of the use of tillage in the organic system, soil carbon concentrations were higher at all depths to 30 cm in the organic system than in the other systems. This accumulation of higher soil organic carbon system was attributed to the incorporation of high amounts of organic inputs from manure, composts, and cover crops in organic system. The authors concluded that if adequate weed control could be achieved in the reduced tillage organic system, this system would provide improved soil quality and yield-enhancing benefits compared to no tillage conventional systems.

Recently, Dulja et al. (2013) also use field trials to analyze the sustainability of organic farming compare to conventional farming in olive production systems in Alpula region of Italy. To achieve their objective, they use the Environmental Accounting Information System (EAIS) that integrates together environmental and economical indicators. The results of the comparison of the two different agricultural systems indicates that the organic system perform well than the conventional system for some of the indicators used like organic matter input/output and nutrient surplus.

In Africa, Koopmans et al. (2011) presented two case studies on climate change mitigation of agricultural systems. In first, the effect of compost application on soil carbon sequestration is quantified for an arable system on reclaimed soils in Egypt. In second, the effect of different types of shade management on carbon storage in organic cacao agro forestry system is quantified in the Democratic Republic of Congo. Their results show that in the Egyptian desert, the organic farming practice of applying organic fertilizers leads to fertile arable soils, and additional sequestered almost 30 tons of carbon per hectare over 30 years time-span. In the Eastern Democratic Republic of Congo, the results reveal that shade management is a form of resilient agro-forestry that can preserve carbon stocks that amount to a multitude of that in more intensive forms of land use, such as arable land.

Ndungu et al. (2013) analyzed the impact of organic vegetable production system on the profitability of smallholder farmers in two counties of Kenya. They evaluated the impact of the organic production by the mean of propensity score matching method. Their results show that the organic vegetable production system had a positive significant impact of increasing farm gross margin by about US$0.58. Their study recommended the promotion of organic production system as a tool to improve rural livelihood.

The mathematical programming approach is choosed for this study. The reason is that given the empirical nature of the problem and the available data, mathematical programming is certaintly the suitable tool for the analysis. Econometric models which are poweful tool for testing hypothesis provide information on how and and to what extent the explanatory variables affect the outcome. However, the main disadvantage of econometric methods is data requirements. In some cased for example it is not possible to take data regarding some variables from one period and one location and another data from another period and location. This is possible in a mathematical programming or simulation approach.

3.4. Partial Conclusion

After defining the concepts of climate change and sustainable intensification, this chapter describes the theoretical and empirical approaches to bio-economic modeling of agricultural systems. The theoretical review shows that bio-economic models have interdisciplinary orientation in that they help to understand relations between agriculture and the environment. The empirical review presented in this study is a result of two distinct developments: by one side, we review empirical studies based on a bio-economic analysis of agricultural technology adoption in developing countries; and by the other side, we review empirical studies based on the economic and environmental attractiveness of organic farming. Most findings suggest that the organic farming system offers high potential of climate change mitigation with environmental and economic benefits for farmers practicing it.

Chapter 4: Materials and Methods

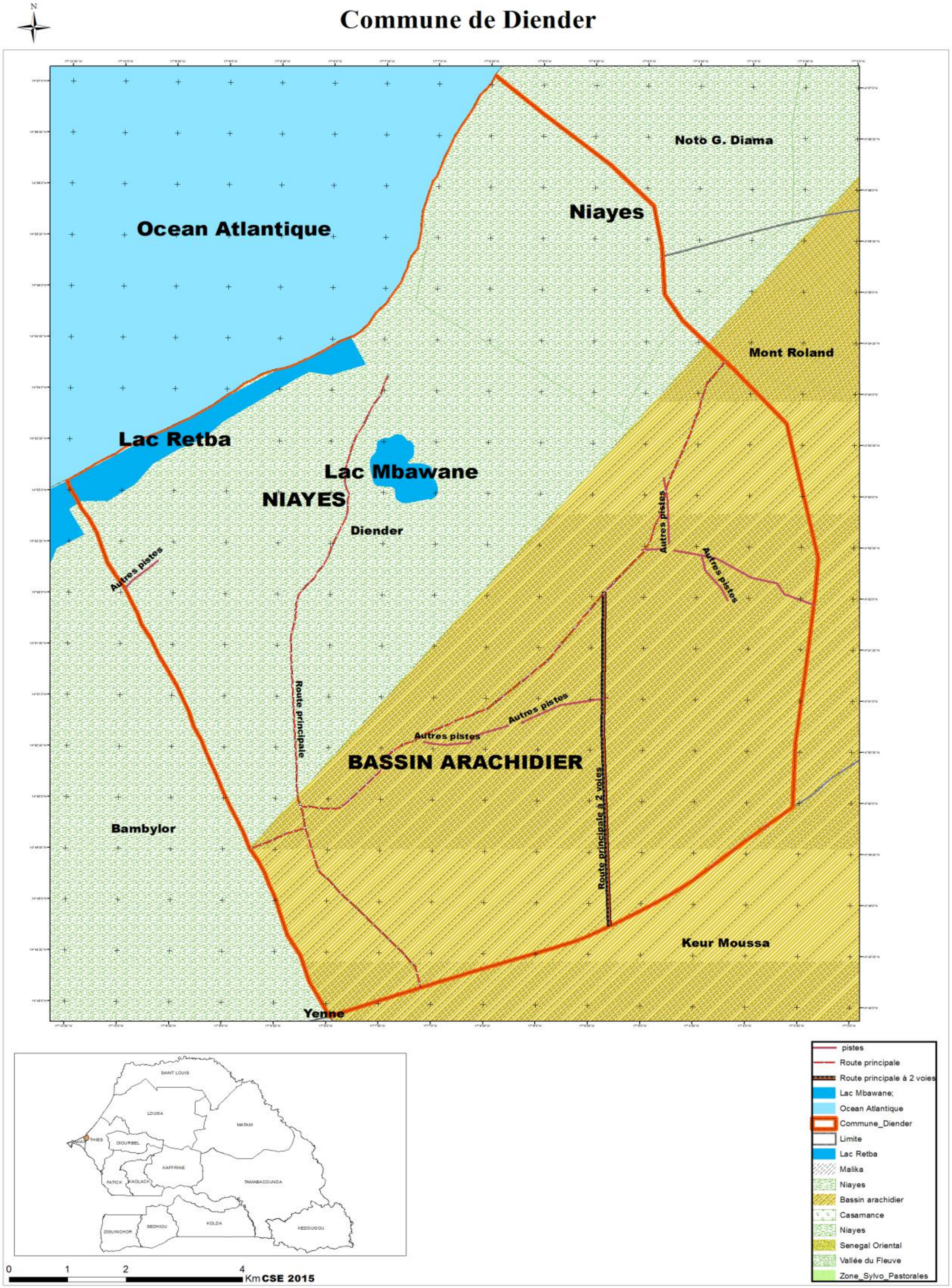
4.1. Introduction

This chapter sheds light on the general characteristics of the study area and on the methodology used to conduct this study.

4.2. The Study Area

This study is carried out in Senegal, in the Niayes Zone, which is the band surrounded by the Atlantic Ocean and located along the axis Dakar – Saint-Louis Regions (see the map in figure below). We have chosen the Niayes Zone as research area because it constitutes, together with the Senegal River Valley, an agro-ecological zone of Senegal that is excellently suited to horticulture and where horticulture production well developed. The Niayes Zone is still the leading horticultural production zone and is the best example in terms of an integrated use of favorable factors of production and marketing (Matsumoto-Izadifar, 2008). About 80% of the national horticultural production comes from the Niayes Zone. This horticultural vocation is conferred by numerous potentialities related to favorable climatic, soil and hydraulic conditions as well as by the proximity to the urban markets. The study is specifically done in the community of Diender which is part of the region of Thies situated in the center of the Niayes where the water table can be easily reached. It consists of 24 villages with a population estimated about 29,000 inhabitants. The geographical features of the rural community of Diender are mainly those of the Niayes where it is entirely located. The map of the rural community is shown in the figure below.

Figure 4.1: Map of the study area in the Niayes Zone of Senegal, West Africa.



4.2.1. Local and Physical Characteristics

The Niayes is a natural region in north-west Senegal stretching from Dakar to Saint-Louis, covering a coastal fringe and hinterland some 180 km long and 5km to 30km wide (Fall *et al*., 2001). Cutting diagonally across the four administrative regions of Dakar, Thiès, Louga and Saint-Louis, this swathe of land is characterized by depressions and dunes lying over a shallow water table, with a network of water courses once rich in lakes and water points. Its coastal location and particular ecological conditions have proved highly attractive since the installation of the first colonial trading posts on the Grande Côte, and its continued economic importance and demographic growth have made the Niayes one of the main centers of human and economic activity in Senegal today.

4.2.2. Climate Conditions

Located in the southern half of the Sahel, the climate of this Sahelian area is characterized by a long dry season from October to June and a short, three month rainy season (Fall et al, 2001). Therefore the area records an alternation of a wet season of about three months and a dry season of about nine months. Rainfall is dedicated by the presence of the monsoon, and average annual precipitations are low. They are scare and rarely exceed 500mm per year in the Dakar region in the south, and 350 mm per year in the Northern part of the Niayes in Saint-Louis (Fall et al., 2001). The region records between December and February polar air from temperate regions that brings in some light and irregular rain (Touré and Seck, 2005). This situation is beneficial for the blossom of fruits and helps regenerate the vegetation during the dry season (Trochain, 1940). The main characteristic of the study area is the microclimate created by maritime trade winds that helps moderate temperatures, with high humidity and frequent night-time dew. The average annual temperature lies between 23.7◦C and 25◦C with the highest average monthly temperatures during the rainy season oscillating between 27.5◦C and 28.1◦C. From November to February, the lowest and highest temperatures are 18ºC and 28ºC respectively. With regard to air humidity, it remains high reaching 90◦C near coastal zone, and dropping to about 15% in the interior of the Niayes.

4.2.3. Soil and farmland

The Niayes region has a topography which is modeled with a succession of sandy dunes and depressions. Three main ranges of dunes are found in the Niayes. The white coastal dunes along the shore are characterized by conchiferous beaches. These shifting dunes have been planted with beefwood to help stabilize them and prevent erosion over the last three decades. Yellow and semi-stable dunes are found behind the coastal dunes where they are developing, interspersed with dried-up lakes and valleys. Finally, red mainland dunes are found in the interior of the area.

According to the type of dune and its position, it can be found a variety of soil types which differ in nature and characteristics. Therefore, the shifting dunes are characterized by sandy soils containing virtually no organic matter. The white and yellow dunes located in the north support small family holdings, where vegetable gardens are tended in the shade of the beefwoods with the help of small, shallow pools of standing water and large quantities of organic matter. The red dunes are covered with the unleashed tropical ferruginous soils found in over two thirds of the Niayes area, which are low in organic matter. During the independence period in the 1960s they were used to grow rain-fed cereals and groundnuts, as well as providing grazing for livestock that alternated between pastures on the dunes and in the basins. However, as rainfall diminished and the demand generated by demographic growth and the developing urban markets increased, the colonial production system sifted progressively towards more productive agriculture based on associated vegetable gardening/ tree cultivation and sedentary livestock rearing, with parallel development of fishing in coastal villages. Today, this part of the Niayes is characterized by the presence of medium and large-scale horticulture enterprises, which often include a poultry or dairy farm.

The Niayes is a region or depressions between the dunes from which the region takes its name, are characterized by shallow basins, patches of groundwater, soils rich in humus and often in peaty sediments. These rich soils are favorable for a wide variety of horticultural production. The lowest part of the basins is used for irrigated and seasonally flooded farming depending on the proximity and abundance of the water table. The basins of the Niayes are very densely occupied because of the richness of its soils, and the proximity of water table. Therefore, the Niayes zone has big potentials for the development of horticulture production. However, in some places, particularly in the south zone of the Niayes, the availability of water is a limiting factor. While in the centre of Niayes, the water table can be reached even with a non-cemented, traditional well at a depth of one meter, in the south zone however, in some places the water table is so deep that the source of water used for irrigation is that of the water corporation. This source of water is expensive and the water constraint has caused some producers to cease their horticultural production completely, while others have partially abandoned by reducing their cropped area.

4.2.4. Water Resources

The zone of Niayes doesn't have a permanent source of water and almost all water in the area is drawn from underground sources. The main reserve is a good quality shallow aquifer that extends across the entire zone between Dakar and Saint-Louis, which is of paramount importance in supplying water for all the area's needs. In addition to the considerable human pressure on it, particularly towards the south, this reserve is also threatened by serious risk from incursions of seawater (Panaudit/Senegal, 1996).

4.2.5. Demographics

The Niayes region is characterized by high population density and market intraregional disparities. Average density is about 200 hab/km^2. The high density of the population in the zone is due to the natural growth combined with inter-regional migration from north to the south, and from the Sahelian hinterland towards the coast. These migratory flows have increased since the mid-1970s, resulting in rapid urbanization. The natural resources of the Niayes are under high and constant pressure due to the opportunities that the area offers by urban markets with more intensive forms of agriculture. This has led to the emergence of progressively inter-related urban and industrial development.

4.2.6. Farm types

The agriculture developing in the Niayes region is highly diversified, ranging from small individual holdings operating under land rental contracts or sharecropping arrangements to large-scale commercial enterprises whose production is primarily destined for the external market. Between these two extremes lies a wide range of family-run farms that perform at varying levels and are involved in markets to varying degrees. There is a growing gap between smallholdings managed by individuals rather than families and commercial farms covering tens if not hundreds of hectares. In addition to their greater surface area and equipment, these commercial farms share a common goal - production for the external market and/or local urban markets. The commercial farmers operating in the regions of Dakar and Thiès focus on developing profitable crops for export, particularly French beans and cherry tomatoes.[12]

With regard to family farms, it is important to underline the fact that they differ, sometimes greatly, in terms of the amount of land available, their water supply system, level of equipment and investment, and amount of non-farm income. Some of them have only very limited technical means at their proposal, while others have recourse to modern irrigation techniques. The general trend is to diversify production in order to improve risk management.

4.2.7. Land holding and tenure arrangement

Farmland in the Niayes area falls into two categories apart from governmental land, private lands, and private lands owned by the state and individuals. They are land from village lands, and farmland located within urban areas. Over 80 % of the agricultural lands in the Niayes area are village lands located within rural communities. These lands are managed by rural councils, which allocate them to members of the rural community. Allocation gives the beneficiary non-transferable use rights, and is determined according to the applicants' capacity to ensure that the land is put to productive use, either individually or with help from the family. The legislation also states that: "persons occupying and cultivating land on public lands at the time when the law comes into force may continue to occupy and farm them under the terms and conditions of allocation". The rural council can only withdraw land if beneficiaries cease to use the plot themselves, or if the productive use is deemed to be insufficient.

Land may also be withdrawn for general interest. Alongside the land allocated to individuals and groups, some lands remain unallocated. These are most commonly found in rural communities situated in north Rufisque. These lands were to be used collectively and are now managed by the rural council, which can allocate plots to applicants wishing to put them to productive use. There are unlearned lands, areas used for grazing, wild harvesting and woodcutting. In practice, farmers have free access to the resources found on these lands. Farmlands located in urban areas are managed by mayors and municipal councilors, often in conjunction with the town planning department. Over the last decades, municipal authorities in towns whose territory includes lands have given housing and job creation a high priority then urban agriculture, pursuing an

[12] Touré and Seck (2005)

independent policy of parceling and selling off public lands to urban developers and allocating land to property developers and industrialists. Market gardening basins have been filled in, local farmers driven out, and numerous conflicts have arisen as local people opposed to these decisions and operations claim customary over the land.

4.2.8. Agriculture Production in the Niayes

The Niayes zone has climatic and soil conditions that are favorable for a broad range of vegetable garden. The production period is virtually the same for all farms, lasting from October/November to May/June, and corresponding to the cold dry season (November to February) and the hot dry season (March to June). Farmers avoid cultivation during the rainy season even though they know the price of vegetables increase during this period because of its scarcity. This is partly due to the presence of high levels of parasites and associated cost of prevention and/or treatment, but also to difficulties of conserving products in the hot/humid condition of the rainy season. Although they all grow many varieties at the same time, family farmers and commercial farmers use different strategies to select their crops and manage their farms. Family farmers mainly grow eggplant, cabbage and tomatoes (vegetables designated for the local market, to be used in everyday cooking). Commercial farms, on the other hand tend to produce vegetables for export (bean), those used in European-style cooking (bean, potatoes) or which are hard to come by certain times of the year (groundnut, cabbage). They are also interested in some of the dry-season crops that are highly profitable, but which require greater investment and technical expertise. Crop selection is determined by taking into account the soil characteristics of the production sites. Within the small basins of shifting sand scattered across the dune belt, the production is focused on beans, onions, cabbage and tomatoes and to a lesser extent, eggplants and watermelon. In the inter-dunal depression of the interior, poultry farming is associated with fruit trees (papaya, banana, coconut, mango, palm wine, etc.). Two types of vegetables gardening are found in this zone, determined by water table below: seasonally flooded crops (tomato, sweet potato, and onion) and the irrigated crops usually found in the driest parts of these depressions. The production can continue throughout the year in these sectors if the farmer has mastered the appropriate crop technologies and has the financial means to buy the products needed to protect them during the raining season. Horticulture production in this area is largely dependent on the use of water resources from water table and inputs such as selected seeds and fertilizers. The productivity of the existing systems varies greatly from one farm to the other. This is due to several factors such as the irrigation system, technical expertise and consumption of inputs.

Modern agriculture has gradually replaced traditional agriculture in the Niayes region by developing a production for marketing. It intensifies the production by the increase use of fertilizers and pesticides that enable the increment of yields in the short term. But the intensification of agriculture associated with population growth and unstable climate conditions (chronic rainfall deficit) is reversing the gain of farmers. It is noticeable in different areas of the Niayes the degradation of natural resources with repercussions on all rural activities (production, processing, etc.). In addition, in Senegal, agricultural policies are most often defined without the involvement of actors and without long-term vision that promote the management of climate change. This situation has pushed producers and families of small farmers in a precarious situation that limit their potential for innovation and to improve income from production.

4.3. Data Collection Methods

Semi-structure questionnaire were used to collect primary data on organic and conventional farming practices. We use purposive sampling technique for the selection of conventional and organic farms. A sample of 40 farms is selected consisting of 20 each from conventional and organic farms in the rural community Diender during the agricultural year of 2014-2015. A farm of 1.5 ha from each system (organic and conventional) is selected to apply linear programming approach that reflects the situation of organic and conventional farming systems in the study area. The survey was conducted in one agricultural year 2014-2015 and data for risk analysis was collected for three consecutive years (2012, 2013, and 2014). Data is also collected through semi-structure interviews with experts, heads of farmer's organizations, and focus group discussions. In addition, we gathered information from national structures, international institutions, NGOs (such as Enda Pronat), and local associations. These include the following: in Keur Moussa, "*la fédération des agriculteurs de Keur Moussa*" (Woobin) and in the Diender, "*la fédération des Agropasteurs de Diender" (FAPD).* Moreover, From Jun 2014 to May 2015, we did a survey at different seasons to get information about selling and buying prices from market agents and consumers. The survey was done in three big markets in Dakar where vegetables are mostly sold. These are Thiaroye, Castor and Tilène. Consumers living around those markets were also interviewed. In addition, we interviewed sellers and buyers at the market village in the rural community of Diender. In this case study, a sampling was not needed since we are not doing a deep study of the marketing channel and the percentage of the production that flows through each circuit. Overall, we interviewed about 80 respondents with 5 interviews in each case (wholesalers, retailers, consumers and producers) and each market. All the information was imputed in an excel file and average prices are used to do our analysis. The number of vegetable crops is limited to three due to lack of full information related to the other crops.

We have observed that many farmers are not adopting 100 percent organic practices because they are doing it progressively, but for our study we consider those that have totally adopted the system. Our questionnaire was improved by the mean of pre-testing that has been done one week before the data collection. From the organic farming system, we found a number of farming practices such as crop rotation, green manuring, use of cover crop, application of animal and compost manures, and the use of natural pest control mainly from nime trees. On the other hand, the conventional system is characterized by practices like the use of chemical fertilizers (urea and ammonium), the use of chemical pesticides, crop rotation, and to some extends the application of poultry manure. In the Diender, farmers use water from well for irrigation.

4.4. Modelling framework

4.4.1. Bio-economic optimization models

Mathematical programming (MP) models are optimization models widely used for analysis in agriculture and economics. They have an explicit objective function that is maximized or minimized subject to a set of constraints. Buysse et al. (2007) justified the motivation for using programming models in agricultural economics in that, the fundamental economic problem is how to make the best use of limited resources. A mathematical programming model from an analytical perspective tries to identify an extreme (i.e., minimum or maximum) point of a function f (X1, X2,…, Xn), that satisfies a set of constraints such as g(X1, X2,…, Xn) ≤ b (Dantzig, 1949; Kantorovich, 1966). So, mathematical programming models offer great possibilities to formulate a wider range of actual and potential activities and to determine their relative attractiveness.

There exit a wider range of different mathematical programming, from disaggregate single farm optimization models to highly aggregated sectoral models (Heckelei et al., 2001). Mathematical models can take many forms, including but not limiting to dynamic systems, statistical models, differential equations, or games theory models (Ugwa and Agwu, 2012). Following Hazell and Norton (1986), a typical mathematical programming model is written in the following form:

Max Z = $\sum_{i=1}^{n} C_i \, X_i$

St $\sum_{i=1}^{n} A_{ij} \, X_i$ ≤ Bj all j=1… m

And Xi ≥ 0 for all i= 1…n

Where Z is called the objective function, X is the vector of decision variables and B is the vector of available resources. The problem is to maximize the value of the objective functions according to the fulfillment of the resources' constraints and the no-negativity requirement. The models have been applied to solve different problems, and aim at providing recommendations about the most efficient or economically rewarding way to run the agricultural activity.

Bio-economic optimization models can be either static or dynamic (Holden, 2005). For the purpose of our study, a static model is utilized. A static model is a model that does not account for the element of time in contrast to a dynamic model. A static programming model optimizes an objective function for one period (i.e. one year) over which decisions are taken (Louhichi et al., 2010a).

3.4.2. The basic model

In order to analyze the economic and environmental attractiveness of organic farming, a static linear programming model is developed for a representative farm from each system (conventional and organic) in the Niayes region of Senegal. Mathematical programming is a suitable technique to analyze and compare the results of different production practices. Our basic model starts with the objective function:

$$Max\ Z = \sum_{(j,t)}^{n} Y_{(j,t)}\, P_{(j,t)} - \sum_{f=1}^{D} \sum_{(j,t)=1}^{n} P_{f(j,t)} Q_{f(j,t)} - \sum_{m=1}^{H} \sum_{(j,t)=1}^{n} P_{m(j,t)} Q_{m(j,t)} - \sum_{p=1}^{V} \sum_{(j,t)=1}^{n} P_{p(j,t)} Q_{p(j,t)} - \sum_{s=1}^{B} \sum_{(j,t)=1}^{n} P_{s(j,t)} Q_{s(j,t)} - \left(\sum_{l=1}^{R} \sum_{(j,t)=1}^{n} w_{l(j,t)} N_{(j,t)} D_{l(j,t)} + \sum_{l}^{R} \sum_{(j,t)}^{n} S_{l(j,t)} N_{(j,t)} T_{(j,t)}\right) - c_{(j,m)} \mathrm{W} \quad (1)$$

Subject to:

$\sum_{p}^{E}\sum_{(j,t)=1}^{n} L_{p(j,t)}X_{(j,t)}L_{(j,t)} \leq L$ (Labor Constraints) (2)

$\sum_{(j,t)=1}^{n} L_{(j,t)}X_{(j,t)} \leq L$ (Land Constraints) (3)

$\sum_{(j,t)=1}^{n} K_{(j,t)}\, X_{(j,t)} \leq K$ (Capital Constraint) (4)

$\sum_{(j,t)=1}^{n} Q_{f(j,t)}X_{(j,t)} \leq Q_{fr}$ (Fertilizer Constraint) (5)

$\sum_{(j,t)=1}^{n} Q_{s(j,t)}X_{(j,t)} \leq Q_{sr}$ (Seed constraint) (6)

$X_{(j,t)} \geq 0$; (j, t)=1...n Non-Negativity (7)

The objective function (1) maximizes is the total of the gross margins of various crop productions.

$Y_{(j,t)} =$ Yield per hectare of the j^{th} activity at cropping cycle t;

$P_{(j,t)}$ =Price of crop j at cropping cycle t;

i= crop activities (tomato, onion, eggplant, cabbage, and Green pepper)

t = cropping cycle (from January to December)

$P_{f(j,t)}$ =Price of fertilizer used for the j^{th} activity at cropping cycle t;

$Q_{f(j,t)}$ = Quantity of fertilizer used for the j^{th} activity at cropping cycle t;

Q_{fr} = Quantity of fertilizer recommended for one hectare

$P_{m(j,t)}$= Price of manure used for the j^{th} activity at cropping cycle t;

$Q_{m(j,t)}$ = Quantity of manure used for the j^{th} activity at cropping cycle t;

$P_{p(j,)}$= Price of pesticides used for the j^{th} activity at cropping cycle t;

$Q_{p(j,t)}$ = Quantity of pesticides used for the j^{th} activity at cropping cycle t;

$P_{s(j,t)}$= Price of seeds used for the j^{th} activity at cropping cycle t;

$Q_{s(j,t)}$ = Quantity of seeds used for the j^{th} activity at cropping cycle t;

Q_{sr} = Quantity of seed recommended for one hectare

$w_{l(j,t)}$= Daily labor wage for temporary workers used for the j^{th} activity at cropping cycle t;

$N_{(j,t)}$= Number of temporary workers used for the j^{th} activity at cropping cycle t;

$D_{l(j,t)}$= Number of temporary labor days used for the j^{th} activity at cropping cycle t;

$S_{l(j,t)}$= Monthly Salary for seasonal workers used for the j^{th} activity at cropping cycle t;

$N_{(j,t)}$= Number of seasonal workers used for the j^{th} activity at cropping cycle t;

$T_{(j,t)}$= Number of months per season used for the j^{th} activity at cropping cycle t;

$c_{(j,t)}$= Price of water used for the j^{th} activity at cropping cycle t;

W= Quantity of water used for the j^{th} activity

$X_{(j,t)}$ = the lievel of the j^{th} activity in hectare (ha) at cropping cycle t;

$L_{(j,t)}$ = Land needed for the j^{th} activity at cropping cycle t;

L = Total Land available to farmer

$K_{(j,t)}$ = Capital (cash)needed for the the j^{th} activity at cropping cycle t;

K= Total available cash capital

$L_{p(j,t)}$ = Number of labor man-days required per hectare by crop j during period p at cropping cycle t;

Our basic model consists of a farm model, a static linear program model for a representative farm of each agricultural system (conventional and organic) which is made up with one objective function and several constraints. We utilize detailed farm level data on crop activities of the farms. Crop activities of our two representative farms consist mainly on irrigated vegetable production such as onion, eggplant, cabbage, green-pepper, and tomato. At first the model takes into accound the main farm activities, which are primarily vegetables production. The mathematical model obtain the optimal farm plans of each farm type. This will be derived from gross margin maximization that is assumed to be the objective of the farmers and is used to measure the economic performance of the farms. Then, a sensitivity analysis and risk analysis based on E-V model are performed to evaluate at which extent farmers of the area are risk averse. Next, the model is used to establish a number of scenarios in order to better comprehend the potential of organic farming to enhance farmers' productivity and mitigate climate change. The level of carbon emissions equivalent is regarded as an indicator of environmental performance.

The maximization problem is estimated through linear programming by using the solver xxx included in the General Algebraic Modeling System (GAMS). Per hectare costs per season in conventional and organic farming systems are estimated by including cash costs (costs of seed, fertilizer, pesticide, manure, hired labor, and other operation costs). The revenue is estimated by multiplying the total production after deduction of the quantity consumed at home with the market price of the product. The gross margin is then calculated as the financial output revenue minus the total costs. The gross margin is expressed in FCFA.

4.4.3. Model Variables

Crops enterprises

Several types of vegetables crops can be grown on the sample farm in the Niayes zone. Five crops that dominate the production system of family farming in the Niayes are included in the model. These are tomato, onion, eggplant, cabbage, and green pepper. The farm is divided into plots. Every crop can be planted each month. In the objective function, the gross margin from crops is included by multiplying the total harvest per hectare by the average market price. The average market prices and yields per hectare vary according to each season .

Labour constraints

Two types of labors are used designated family labor and hired labor. Under each category of labor available, labor allocation is based on the labor requirement of each enterprise during each stage of the agricultural activities. Field operations (land preparation, transplanting/sowing, crop care, hand weeding, water spray and harvesting) have to be performed during a particular period of the season throughout the year. Therefore, the year is divided into seasons lasting each 4 months maximum. The working days are considered to be 25 days (Sunday is an off-day) per month and 8 hours a day (from 7am to 12am in the morning and 3pm to 6pm in the afternoon). In our representative farms, three types of labors are used to perform the different tasks. These are family labor, contract labor/permanent workers and temporary hired labor (only at pick periods such as harvesting). Each of our farms (conventional and organic) required two contracts or permanents workers with monthly wage of 25000 FCFA per month for each worker and an additional charge related to the cost of feeding them estimated about 30,000 FCFA per month. Temporary hired labor vary according to the period, for harvesting the cost is about 1500 FCFA per day/worker and for other operations such as transplanting, hand weeding and land preparation the cost is about 1000 FCFA per day/worker. The number of temporary workers varies also according to the types of crop and tasks. Labor restrictions are measured in man-hours and the restraint levels are determined from the size and composition of permanent workers, average temporary workers and family labor supply per month.

Land constraint

We have two types of farming systems in the study area such as industrial and family farming systems. The average cultivated land allocated for the production of crops varies according to the farming types. The average arable land owned by farmers is used as the upper limit of land constraints. The farms analyzed are typical family farming of the centre zone of the Niayes. In this region, the average farm size for family farming is about 1.5ha. In our analysis, the size and soil type of the example farm is therefore 1.5ha and clay-sandy soil, respectively. Farmers divide their land into several portions growing various vegetables allowing crop rotation and ensuring constant supply of fresh vegetables as they mature at different time.

Capital constraint

Working capital is a limiting factor of production that is determined for the purchase of seed, fertilizer, hired labor costs and transportation costs, etc. working capital is one of the constraints limiting the production level of the farmers. The amount of capital a farmer would invest for vegetable production in a year is considered as the total operating capital available to farmer.

Rotation constraint

Rotation constraints are set on the basis of 0.6 ha per crop per season for the conventional farm and 0.4 ha for the organic farm.

Fertilizers constraint

Fertilizers play an important role in increasing production and the use of the resource is constrained by its high price. The major types of fertilizer considered in the study are urea and NPK for the conventional farm, and poultry manure, cow manure and compost in the organic farm.

Seed constraint

The cost of seed vary according to type of crops, some have very high price such as onion. We consider seed restrictions as to not allow farmers to misuse seeds.

Climate factors

Climate variables are included indirectly in the model based on their impacts on yield. The main greenhouse gas emissions from crop production are Nitrous Oxide (N_2O) emissions from fertilizer used, and methane (CH_4) from livestock. To measure the environmental performances of our two systems, we analyze the effect of a carbon emission equivalent reduction on the gross margin of each farm. Carbon emission is the primary greenhouse gas emitted by human activities and agriculture is part of the main emitter of that gaz. Emissions from fertilizers and pesticides application are obtain by following the IPCC conversion equivalent of CO_{2-eq} (IPCC, 2007) , and for manures we follow the work of Mogensen et al.,2011. In our analysis, CO_{2-eq} is obtained from nutrient N content in each kg of fertilizer or pesticide used. So we first consider the total nitrogen content in the total amount of fertilizer, manure and pesticide used to grow each type of vegetable consider in this study. Then we calculate the carbon equivalent of that amount of nitrogen for each vegetable crop.

4.5. Risk in the farm model

4.5.1. Theory of risk in economic analysis and risk approaches

Agriculture is an activity that involves a relatively high level of risk and uncertainty than some other activities. Risk is mostly considered as uncertainty with consequences (Blackburn et al., 1994, Hardaker et al., 1997, Cross, 2000). It is therefore measured in terms of consequences and occurs when there is a chance of something happening that will have an impact upon objectives. Farming is a risky business because of the inherent variability of the natural environment in which it is conducted and the markets in which its products are sold (Beal, 1996). In addition, agricultural prices are volatile as a result of variation in many production factors such as climate, demand, yields, pest and diseases incidence (Cummins and Santomero, 1999). Farmers face a number of risks which can be divided into production risk and price risk (Hardaker et al., 1997). Production risk is related to the variation in output arising from weather, pests and diseases, input quality and availability, the inherent variability of biological systems, and technological change. The most important risk management function on the farm is the control of production variability (Gaynor, 1998). When the variability in production is not well manage by farmers, they will fail to use good price risk management techniques, as they will not have enough produce to sell. Unfortunately, production risks are likely to increase further in the future because of various issues related to climate change. In recent years, many scientists have warned that the earth's climate is changing and are now sure that global changes (for example the enhanced greenhouse gas effect and consequent global warming) will increase the risk burden on agriculture (Peters et al., 2006). Price or market risk however is related to risks associated with changes in the price of outputs or of inputs that may occur after the commitment to production has been made (Harwood et al., 1999). According to Gaynor (1998), the risks faced in the agricultural produce market include changes in world price, changes in rates, price penalties for low quality produce, problems in shipping produce, and delay or non-payment for goods. However, in the case of Senegalese vegetable producers, one of the most important market risks is price volatility. In general, when the price of a particular commodity is high, farmers tend to produce more of that commodity and consequently prices will fall due to over- production of that commodity. Prices are theoretically governed by the laws of supply and demand but there has been considerable institutional intervention in the agricultural market in many countries leading to world prices fluctuations for many agricultural commodities.

Farmers have many strategies for managing risk. Generally, the management task facing famers is to choose a combination of risk management strategies that best suits the unique conditions of their particular farm and their personal circumstances. Meuwisssen et al, (1999) distinguished two types of risk management strategies: (1) strategies concerning on- farm measures; and (2) risk- sharing with others. On- farm strategies concern farm management and include selecting products with low risk exposure, choosing product with short production cycles, diversifying production, and holding sufficient liquidity. Risk- sharing strategies include marketing contracts, production contracts, vertical integration, hedging on futures markets, participating in mutual funds, and insurance.

Agricultural economists have been concerned about gaining understanding of farmers' decision-making behaviour when confronted with risk, and they have been interested in developing tools to address farmers' decision-making in the presence of risk (Coble and Barnett, 1999). Therefore, various risk modelling techniques have been developed over the last 50 years to address risk in the agricultural decision-making (Visagie et al., 2004). According to Visagie et al. (2004), three approaches to risk and uncertainty programming have been used, namely those requiring no probability information, safety first approaches, and expected utility maximization. The first approach refers to game theoretic models that that are used to find a pure or mixed strategy that optimizes an objective function (wises and aspiration) of a decision maker under different constraints and limitations of resources. Under uncertainty, decision problems exist when no probability distribution can be attached to the states of nature. This means that there is no information on the likelihoods of these states. These models constitute one of the main conventional approaches to agricultural decision-making under uncertainty (Mcinnerney JP, 1967 and 1969). The decision maker's problem in this approach is described as a two-person zero-sum game. In addition, all the risk and uncertainty components facing the decision- maker can be summarized as composite contribution by the player called nature (Hazell and Norton, 1986). However, a clear definition of "nature" and the decision- maker is important in the game theory framework for agricultural production. There are three key features of games against nature namely, the existence of a decision- maker (the farmer for example who is considered as the only rational player of the game), the decision- maker has a set of n possible strategies or actions to follow, and the existence of a set of h different possible states of nature representing the uncertainties within which the decision- maker operates. Such games according to Romero and Rehman (1989) are represented by an n x h matrix whose $(i,\tau)^{th}$ element represents the outcome of the game when the decision- maker chooses the i^{th} strategy to face the τ^{th} state of nature. Many criteria have been used to represent the aspiration of a decision- maker in the game theory model (Hazell and Norton, 1986). Some of them that have been applied in agricultural decision- making under uncertainty are (1) the maxmin (Wald criterion), (2) the minimax regret (savage criterion), and (3) the benefit criterion. The second approach which is the safety- first approach to risk programming is used where a decision problem's primary aim is to satisfy a preference for safety when making decisions about agricultural activities. Various safety first criteria have been discussed. Safety first rules usually discussed three approaches: (1) a decision-maker maximizes expected return subject to the constraint that the probability of income below some specific level is small enough (Telser'rule); (2) the decision- maker maximizes income at the lowest confidence limit, subject to the constraint that the probability of income being lower than the lower limit does not exceed a specified value (Kataoka's rule); and (3) the decision-maker minimizes the probability that income will be lower than some specific level (Roy's rule). However, according to Atwood et al. (1988) both Telser's and Kataoka's criterion involve enforcing probabilistic constraint in the form: $P_r(Z < g) \leq {}^{1}/_{L} *$, where, Pr (.) is the probability of event (.), Z random variable income, g is a goal associated with Z, and ${}^{1}/_{L} *$ is an upper limit on $P_r(Z < g)$. Therefore, enforcing such probabilistic constraints in optimization model can be difficult the income distribution is non-normal or the income distribution is affected by endogenous model decision. The third approach to risk and uncertainty programming which is the expected utility maximization is used in this study to deal with risk and therefore will be discuss in a section below.

Generally, it is assumed that farmers are risk-averse (Mclay et al., 1996, Meuwissen, 2001b, Hall et al., 2003). This means that they are willing to pay a premium to reduce exposure to risk. Most of them prefer a smaller gain which is certain to a larger gain which is uncertain. Many empirical studies have shown that farmers behave in a risk-averse manner (Dillon and Scandizzo, 1978; Young, 1979; Binswanger, 1980; Bond and Wonder, 1980; Brennan, 1981).

There is a limited amount of research on horticultural Senegalese farmers risk attitudes and this deficit needs to be addressed. This study seeks to fill the gap by investigating risk attitudes in the vegetable conventional and organic farming systems in the Niayes.

4.5.2. The Mean-Variance (E-V) Model

The E-V model is based on the expected income-variance criterion which assumes that a farmer's preferences among alternative farm plan are based on expected income E(Y) and associated variance V(Y) (Hazell and Norton, 1986). The expected Value Variance (E-V) analysis was first developed by Markowitz for its application in mathematical programming. It is a model which is the Quadratic Programming approach to incorporating a mean- variance criterion in the objective function. The E-V model allows an analysis of the farmer's profit maximizing production strategies under different risk aversion levels (Scott and Baker, 1979). The solution of the optimization problem yields a bundle of efficient portfolios, meaning that the farmer rationally restricts his choice to those farm plans for which the associated income variance are minimum for given expected income levels (Hazell and Norton, 1986).Though sometimes criticized in the past, it has been shown to be consistent with the expected utility theory (Freund, Markowitz, and Meyer).This model is designed to achieve the third objective of this study which is to analyze risk behavior in both organic and conventional vegetables farming in the Niayes. Following the Markowitz mean-variance efficiency model, the basic empirical model can be written as follow:

$$Min\ V = \sum_{(j,y,t)=1}^{N} \sigma_{(j,y,t)} X_{(j,y,t)} \qquad (1)$$

Subject to:

$$E = \sum_{(j,y,t)=1}^{N} X_{(j,y,t)} e_j$$

$$A_x \leq b \ and \ x \geq 0,$$

Where $\sigma_{i(j,y,t)}$ is the variance covariance matrix of (unit) of reel net revenues or net returns (gross margin) from different crops e_j , $X_{(j,y,t)}$ is the amount of land allocated to crop j at cropping cycle t on year y, E is a vector of mean or expected revenues or net returns (expected gross margin in the case of this study), A is a matrix M x N of technical coefficients associated with resource constraint b, and V is total enterprise or variance of gross margin of the farm. Solution of (1) yields the minimum variance for associated expected gross margin level E. the E-V approach seek to generate the so-called efficient frontier and then select an optimal farm plan from the set of efficient risky production activities, which maximizes the farm manager's utility. The efficient set can be generated E= σ(v) as e is varied (Hardaker, Huirne, and Anderson 1997). Then the problem enterprise plan is determined by solving,

$$E(U(E)) = E - 0.5r_a * Var(E) \quad (2)$$

The farmer's decision problem accounting for different degree of risk of risk aversion is set up as:

$$Max\ E(U(E)) = \sum_{(j,,t)=1}^{N} X_{(j,,t)}\, e_j - 0.5r_a \sum_{=1}^{N} \sum_{j=1}^{N} \sigma_{ij}\, X_i X_j$$

(3)

Subject to:

$A_x \leq b\ and\ x \geq 0,$

Where, e_j is the expected real net return from crop j, X_j is the amount of land allocated to crop j, o.5 is a constant, r_a is the absolute risk aversion parameter and σ_{ij} is the variance covariance matrix of gross margin or real net income, A and b are the same M x N matrix of restriction and vector of resources as in equation (1).

The objective of the farmer is the maximization of net returns above selected variable costs less the risk aversion coefficient multiplied by the variance of net returns. Each farm is assumed to have 1.5ha of cropland available and grow five types of vegetables (onion, eggplant, cabbage, green pepper, and tomato) in a maximum rotation of 0.8ha in the conventional farm and 0.6ha in the organic farm. The model results will give an approximation of the subjective expected utility, given different levels of expected income and risk aversion.

For this study, farm income (gross margin) calculations are carried out for 2012-2014 using observed data. The reason to use a three- years period is that farmers were not able to remember information about yield and prices beyond that period.

Chapter 5: Results and discussions

5.1. Survey Results

The findings of the survey and farm observation reveal that the mean age of farmers surveyed was about 46 years in the organic system, while in the conventional system it was about 45 years. Gender analysis show that there were more females involved in organic farming than in conventional farming (out of 20 farmers interviewed in the organic system 9 were female and out of 20 farmers interviewed in the conventional system only 5 were female). The average farmers were married and the family members (head of household, spouse and children) were the source of family labour. The different crops produced by farmers were cabbage, tomato, eggplant, onion, bitter eggplant, cucumber, zucchini, parsley and green onion. The average farm size under exploitation was about 1.6 ha in the conventional system and 1.4 ha in the organic system. Therefore we use 1.5 ha as an upper bound for land constraint in the simulation analysis.

5.1.1 Resources use and cropping activities

This section includes observed data which are grouped into three categories; namely cultivated area, cropping activities and labour requirement.

Average land area under cultivation for each crop in both systems

The average land area under exploitation of each system is used for various crops during a year. The land area (ha) used to grow various crops from both systems in the study area is presented in table 5.1. It was found that the land area under cultivation for each crop was greater in the conventional farm compared to the organic farm. According to organic farmers, because of the high risk and the non-existence of a local organic market they cannot cultivate a big portion of the available land.

Table 5.1: Average cultivated area (ha) for various crops in different farms at the study area

	Cabbage	Eggplant	Green pepper	Onion	Tomato
Conventional Farm	0.62	0.38	0.40	0.67	0.37
Organic Farm	0.41	0.24	0.27	0.41	0.27

Crop activities

Cropping activities include growing a different cropping cycle in successive seasons during a year. Outlines of the most commonly used cropping cycles in the two systems at the study sites in the Niayes in a year is presented in table 5.2.

Table 5.2: Cropping cycle

Rainy season	***Cold season***	***Hot season***
Cabbage	Cabbage	Cabbage
Eggplant	Eggplant	Eggplant
Green pepper	Green pepper	Green pepper
	Onion	Tomato
	Tomato	

Table 5.3: Most popular planting month for selected crops in the study area

Vegetables	Months											
	Jan	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Tomato	■			■					■	■	■	■
Egg plant					■	■	■		■	■	■	■
Cabbage	■				■	■	■					■
onion	■	■	■	■							■	■
Green pepper		■	■		■	■	■			■	■	■

Source: survey data, 2014-2015

The better planting date of different crops varies between crops and between seasons. Most crops can be planted at each month depending of the farmer. However, some crops cannot be grown in the rainy season due to high prevalence of pest and diseases. Some vegetable crops are sown directly while others are transplanted after the seeds have been raised in a nursery.

Labour requirement

Labour requirement for different crops depend on the crop type and farming system. It was observed that the organic farm rely more on family labour compared to the conventional farm.

Table 5.4: Labour required (man/hours) in the production of different crops in the two systems

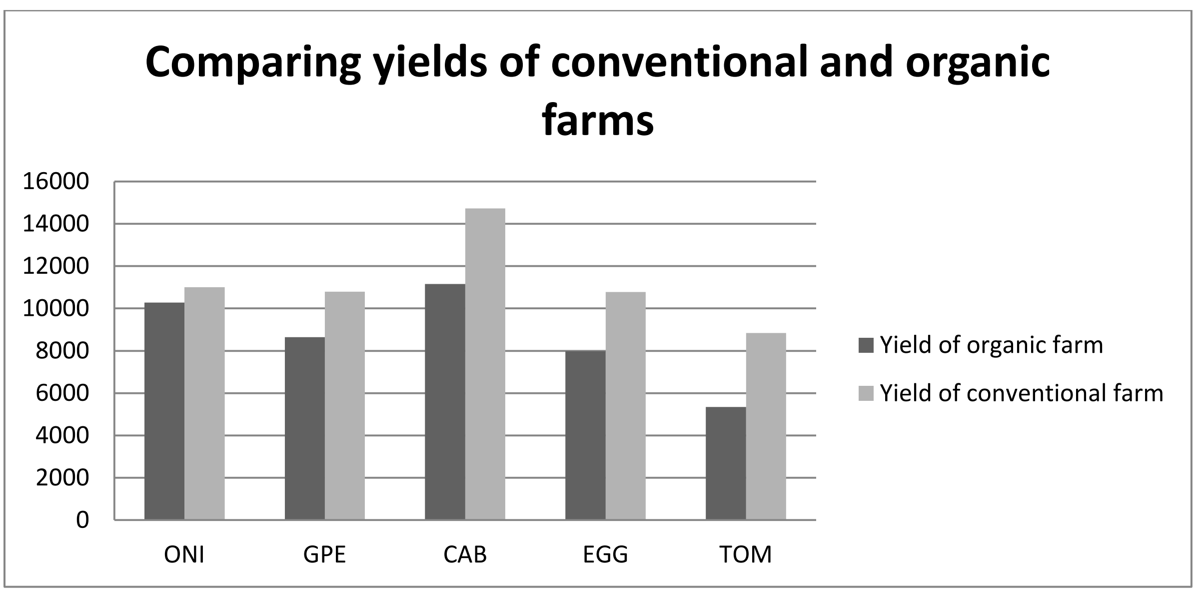
Crops	Conventional Farm		Organic Farm	
	Hired labour	Family labour	Hired labour	Family labour
Cabbage	200	32	216	40
Eggplant	216	32	184	40
Green pepper	216	20	184	30
Onion	240	32	240	40
Tomato	200	20	216	30

5.1.2 Economics of crop production

The gross margin of each crop for each system is presented in the following tables (table 5.5 and table 5.6). In addition, we present in table 5.7 the gross margin of organic crops with a premium price. We present in these tables the yields, prices, and costs of cultivation, gross income per hectare and the gross margin for each crop per hectare. It was not an easy task to determine reliable costs of production (factor input costs such as land and labour, non-factor input costs such as fertilizers, manure, seed, pesticides, organic pesticides, irrigation, etc.). In spite of some difficulties, we had enough reliable data to compare the two systems of production. As it can be seen in the tables the gross margin of the conventional farm is higher than the gross margin of the organic farm for all crops considered. Even with high total cost observed in the conventional farm, yields and revenues were higher in the conventional farm. Thus, conventional farmers of the vegetable sectorin the Niayes region seem to have higher revenues compared to organic vegetable farmers due probably to the non-existence of a local market for organic products and to the lower yield observed in the organic farm.

Analysis of yield per hectare

Figure 5.1: Comparing yields of conventional and organic farms



Source: survey data, 2014-2015

The graph above indicates that yields of all the crops onion, green pepper, cabbage, eggplant and tomato analyzed are higher for the conventional farm. The difference between onion yields is small while the difference for the other crops is much higher.

Table 5.5**:** Average yields, revenue and costs per ha for different conventional crops at different seasons

CROPS	YIELDS IN HA			PRICES IN CFA			REVENUES IN CFA			COSTS IN CFA			GROSS MARGIN IN CFA		
	T1	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*
Onion	11000	11000	0	125	150	200	1375000	1650000	0	779750	779750	0	**595250**	**870250**	**0**
Green pepper	10798	10798	8000	300	500	800	3239400	5399000	8638400	843750	843750	843750	**2515650**	**4675250**	**7794650**
Cabbage	14720	14720	10720	100	150	300	1472000	2208000	3216000	877750	877750	877750	**594250**	**1330250**	**2338250**
Eggplant	10782	10782	6382	75	109	200	808650	1175238	2156400	630250	630250	630250	**178400**	**544988**	**1526150**
Tomato	8782	8782	0	300	344	375	2634600	3021008	0	599750	599750	0	**2034850**	**2421258**	**0**

Table 5.6: Average yields, revenue and costs per ha for different organic crops at different seasons

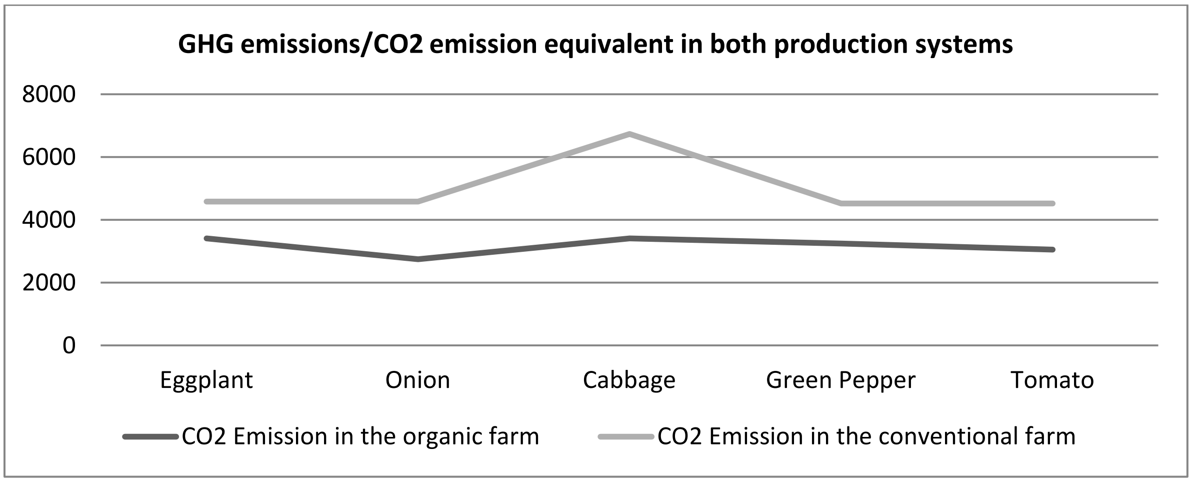
CROPS	YIELDS IN HA			PRICES IN CFA			REVENUES IN CFA			COSTS IN CFA			GROSS MARGIN IN CFA		
	T1	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*
Onion	10280	10280	0	125	150	200	1285000	1541000	0	720000	720000	0	**565000**	**822000**	**0**
Green pepper	8640	8640	5640	300	500	800	2592000	4320000	6912000	723500	723500	723500	**1868500**	**3596500**	**6189000**
Cabbage	11156	11156	8156	100	150	300	1115600	1673400	3904600	643000	643000	643000	**472600**	**1030400**	**1803800**
Eggplant	7980	7980	5890	75	109	200	598500	1197000	1178000	580500	580500	580500	**18000**	**289320**	**597500**
Tomato	5344	5344	0	300	344	375	1603200	1838336	0	575000	575000	0	**1028200**	**1263336**	**0**

Source: Own computation from survey data, 2014-2015

5.1.3 Environmental indicator analysis

Our environmental indicator consists of carbon emissions equivalent obtain through nitrogen contents in each type of fertilizers and pesticides. The detail calculation of carbon emissions equivalent can be found in appendix A. Figure 5.2 below shows the carbon emissions equivalent per crop of both systems. Carbon emissions equivalent are higher with the conventional system than with the organic system. The analysis per crop shows that the production of cabbages and eggplants has the highest level of GHG emissions. This is explained in that the production of cabbages and eggplants require a higher level use of pesticides to fight insects and worms.

Figure 5.2: Comparison of GHG emissions in the two production systems



5.2. Simulation Model Results

To compare the vegetable organic and conventional farming systems in the Niayes zone, economic and environmental simulation results are analyzed and compared. The results are presented under four sub-headings, namely technical results, economic results, environmental results and sensitive analysis.

5.2.1. Technical results

The optimal farm plan for organic and conventional farming for the three seasons is presented in table 5.7. The results show that the gross margin is maximised by the combination of five crops, namely onion, green pepper, cabbage, eggplant and tomato. As it can be seen from the table below, the cropping cycle and the land area allocated to each crop vary according to the system of production. We have five planting months in the conventional farm (April, May, July, September, and December) and four planting months in the organic farm (April, May, September, and October). The results also show that land is not fully used in both systems because of the labor constraint. The conventional system has used slightly more land than the organic system. In contrast to many findings (Acs et al., 2006 ;), labour use is slightly greater in the conventional system compared to the organic system because there is more land used for cultivation in the conventional system. April and May are the peak labour requirement seasons in the organic farm while in the conventional farm the peak labour requirement is in May. The quantity of water used for irrigation is slightly higher in the conventional farm compared to the organic farm because the system of production based on organic farming helps to retain soil moisture and humidity, because of the use of animal manure and compost as fertilizers, but also the practice of mulching and inter-cropping. GHG emissions are also higher in the conventional farm, but both systems are emitters.

Table 5.7: Optimal farm plan of the two systems in different cropping cycles

Crops	**Conventional System**					**Organic System**			
	T4	**T5**	**T7**	**T9**	**T12**	**T4**	**T5**	**T9**	**T10**
Onion					0.600				0.400
Green pepper		0.600					0.400		
Cabbage	0.037	0.563				0.400			
Eggplant	0.072		0.126			0.400			
Tomato				0.600		0.057		0.343	
Total area	**0.109**	**1.163**	**0.126**	**0.600**	**0.600**	**0.857**	**0.400**	**0.343**	**0.400**

T1*T12= Cropping cycles (from January to December)

Source: survey data, 2014-2015

5.2.2. Economic results

The economic results of both farming systems are shown in the table 5.8 below.

Table 5.8: Annual gross margin in organic and conventional systems

	Organic farm	Conventional farm	Mix organic and conventional farm
Gross margin (CFA)	4,431,600	8,252,164	
Gross margin with premium prices	6,112,137		
Gross margin in a "win-win" situation			10,407,870

Source: Survey results

The gross margin of organic farming is much less than the gross margin of conventional in both situations. However, when we perform the simulation with organic crops at a premium price, the organic farm is better off (an increase of gross margin about 27.5 %) compared to a situation where there is no local market for organic crops. Even with premium price, the conventional farm performs better with a gross margin greater about 25.9% than the organic farm. Further, when we allow the conventional farm to partially adopt organic farming, we get a better economic situation (a “win-win’ situation) for farmers. Therefore, conventional farming system performs better economically than organic farming in vegetable production in the Niayes region. These findings are in contrast to findings from some studies carried out in European countries and the United States where organic prices compensate for the lower production but also with some African countries (Langley et al., 1983; Van Mansvelt and Mulder, 1993; Stockdale et al., 2001; Mahoney et al., 2004; Acs et al., 2006; Tanrivermiş H (2008); Delbridge et al. 2011; Delbridge et al., 2013; Ndungu et al., 2013).

5.2.3. Environmental results

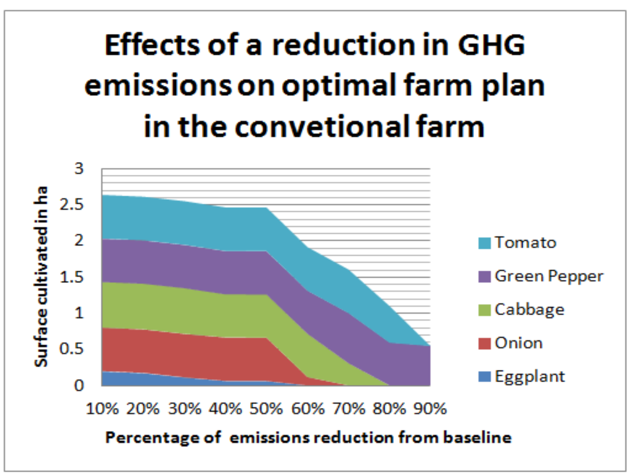
The environmental performances of the two systems were analysed by applying a constraint to GHG emissions in the model. Specifically, the regulation consists of reducing the level of GHG emissions (carbon emissions equivalent) progressively and observing its effect on the gross margin of each farm (organic and conventional) and on the optimal farm plan as well. The results of the simulations are shown in table 6.9 below. With no restrictions, the emissions of GHG from the conventional farm are higher than those of the organic farm for all five crops consideredAs it can be seen from the table below, the conventional system is more sensitive to policies of GHG emissions abatement. Up to a reduction of 80%, there is no change in the gross margin of the organic farm, while for the conventional farm a reduction of 20% of GHG emission led to a reduction of the gross margin of about 0.30%. At 50% emissions restruction the conventional farm abandons cultivation of certian crops (see figure5.3 below) and its gross margin has decreased by 2.56%. At an 80% decrease, the organic farm observes an income lost of about 7.82% while the conventional farm suffers from a lost of about 34.77%. Therefore, farmers can survive better in an organic farming system of production compared to a conventional farming system when a policy consisting of reducing GHGs emissions is applied. Thus mitigating climate change is more effective in the organic system than in the conventional system. Howerver, further environmental analyses are needed to make full assessment.

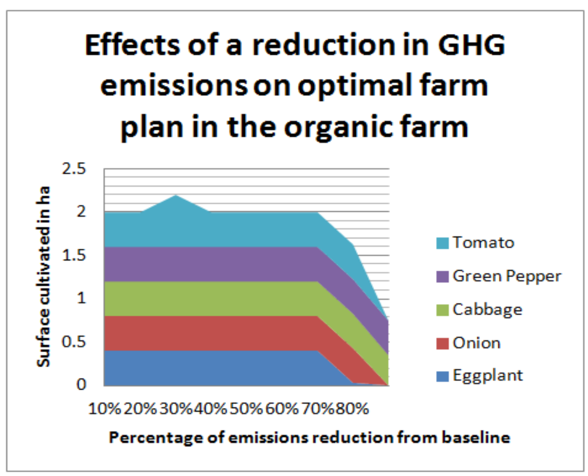
Table 5.9: Impact of a decrease in CO2 emissions equivalent on the gross margin of each system

	Organic Farm		Conventional Farm	
	Gross Margin	Rate of degrease in (%)	Gross margin	Rate of degrease in (%)
Baseline	4,431,600		8,252,164	
10% decrease in CO2 emission equivalent	4,431,600		8,252,164	
20% decrease in CO2 emission equivalent	4,431,600		8,227,186	0.30
30% decrease in CO2 emission equivalent	4,431,600		8,167,518	1.03
40% decrease in CO2 emission equivalent	4,431,600		8,106,774	1.76
50% decrease in CO2 emission equivalent	4,431,600		8,040,887	2.56
60% decrease in CO2 emission equivalent	4,431,600		7,363,196	10.77
70% decrease in CO2 emission equivalent	4,431,600		6,471,770	21.57
80% decrease in CO2 emission equivalent	4,085,161	7.82	5,382,404	34.77
90% decrease in CO2 emission equivalent	2,888,985	57.37	3,737,554	54.70

Source: Survey results

Figure 5.3: Effects of GHG emissions reduction on the optimal farm plan





Source: survey data, 2014-2015

As shown in the figure above, when we reduce progressively the level of GHG in the model the conventional farm starts to reduce the area of land allocated to those crops that emit more GHG. From a threshold of 50% of reduction the conventional farm starts to abandon the cultivation of some crops. However, in the organic farm even with a reduction of about 70%, this has no effect on the optimal farm plan. The environmental regulation starts to have an effect similar to that of conventional farm only from a reduction of 80%. Thus, from this analysis, we can conclude that organic farming is better when it comes to mitigating climate change. However, further environmental analyses are needed in order to get more insights into further issues such as taking into account carbon sequestration.

In summary, an environmental regulation that consists of a reduction in GHG emissions would lead to a "Trade-off" situation where farmers have to abandon cropping patterns that require more inorganic fertilizers in favour of those cropping pattern that emit less GHG. Therefore, an environmental regulation which consists of reducing the emission of GHGs could be an effective tool for policy makers in encouraging farmers to adopt sustainable farming systems such as organic farming in the study area.

5.2.4. Sensitive Analysis

Testing the sensitivity of the model to key parameters is important because it helps evaluate the robustness of the model.

In our model the two farms did not use all the land and all the water available; we focused on capital, labour and crop rotation. Also we tested the robustness of prices. Capital availability is a limiting factor in the conventional farm. An increase of the available capital by one unit will increase the gross margin of the farm by 1.5. Capital is not a limiting factor for the organic farms because the farmer does not buy expensive inputs. With more capital, conventional farmers are able to cultivate more land and increase their income.

For the labour sensitivity analysis, the simulations show that in the conventional farm an increase of one unit of labour in May and July will increase the gross margin respectively by 545 CFAF and 23 CFAF. In the organic farm an increase of one unit of labour in May increases the gross margin by 236 CFAF. When we relax the rotation constraint which consists of dividing the field in portions of land (maximum 0.6 ha in the conventional farm and 0.4 in the organic farm) to allow farmers to grow more diverse crops, we found that it will lead to a specialization in one type of crop in both farming systems (green pepper which is the most profitable per unit of land). The annual gross margin is also higher compared to the baseline scenario, 14,705,080 FCFAF in the conventional farm and 12,002,350 FCFAF in the organic farm. This seems to be the best situation for the two farms economically, but this situation is far from the reality. In fact, in the study area farmers are practicing mixed-farming by growing many types of crops on the same farm. This is to help them avoid losses due to non-existence of conservation units (in case they are not able to sell all in the short term) and a local market for organic crops.

Relaxing the rotation constraint to free the choice of crops and enjoy a higher income would be more profitable, but because farmers take into account production risks in their decision this would not be an option for farmers in the study area. Unless actions are taken to provide them with processing factories, farmers in the Niayes region will divide their land in small portions to grow a variety of crops.

5.2.5. Expected Value Variance (EV) Results

First, we analyzed the variance and covariance matrix which can help us determine whether the source of risk associated with each crop is due to yield, output prices or cost variability or due to a combination of them. Second, we derived the efficient frontier my minimizing the risk given different levels of expected total gross margins. These results shows the potential combinations of crops that give the highest expected risk adjusted gross margins for the conventional and organic farms. Finally, we present the results from the Expected Value- Variance (EV) analysis by maximizing expected utility subject to different levels of risk aversion parameters.

5.2.5.1. Analysis of the variance and covariance matrix of different crops

From the table below we can see that in the conventional farm, green pepper has the highest gross margin variance followed by tomato, cabbage, onion and eggplant. Green pepper is the riskiest in terms of its own gross margin variability. However, this crop is still attractive to farmers as its gross margin is negatively covariated with onion and tomato. Moreover, green pepper is an important crop for farmers as it has the highest price among other crops (see table 5.5). Therefore, source of risk associated with green pepper could be due to prices. Tomato has a gross margin's variance following green pepper as it has the lowest yield and cost compared to the other crops (see table 5.5). Cabbage occupies the third place with respect to the gross margin's variance even though it has the highest yield (see table 5.5) compared to other crops grown in the farm.

Table 5.10: Variance and covariance matrix of crops considered in the conventional farm

	Onion	Cabbage	Green pepper	Eggplant	Tomato
Onion	**1.9788E+11**	-2.85488E+11	-3.54878E+11	-44275453000	5.70768E+11
Cabbage	-2.85488E+11	**7.66549E+11**	1.34259E+12	1.97923E+11	-9.50835E+11
Green pepper	-3.54878E+11	1.34259E+12	**2.5816E+12**	3.93323E+11	-1.3219E+12
Eggplant	-44275453000	1.97923E+11	3.93323E+11	**60568429082**	-1.75848E+11
Tomato	5.70768E+11	-9.50835E+11	-1.3219E+12	-1.75848E+11	**1.69207E+12**

Note: Bolded figures are the variance and other figures are the covariance.

Table 5.11: Variance and Covariance matrix of crops considered in the organic farm

	Onion	Cabbage	Green pepper	Eggplant	Tomato
Onion	**1.76826E+11**	-2.07418E+11	-1.33088E+11	-85168703334	2.79971E+11
Cabbage	-2.07418E+11	**4.46897E+11**	6.11379E+11	1.9352E+11	-3.69108E+11
Green pepper	-1.33088E+11	6.11379E+11	**1.11821E+12**	2.73442E+11	-3.01732E+11
Eggplant	-85168703334	1.9352E+11	2.73442E+11	**84068284134**	-1.53563E+11
Tomato	2.79971E+11	-3.69108E+11	-3.01732E+11	-1.53563E+11	**4.51417E+11**

Note: Bolded figures are the variance and other figures are the covariance.

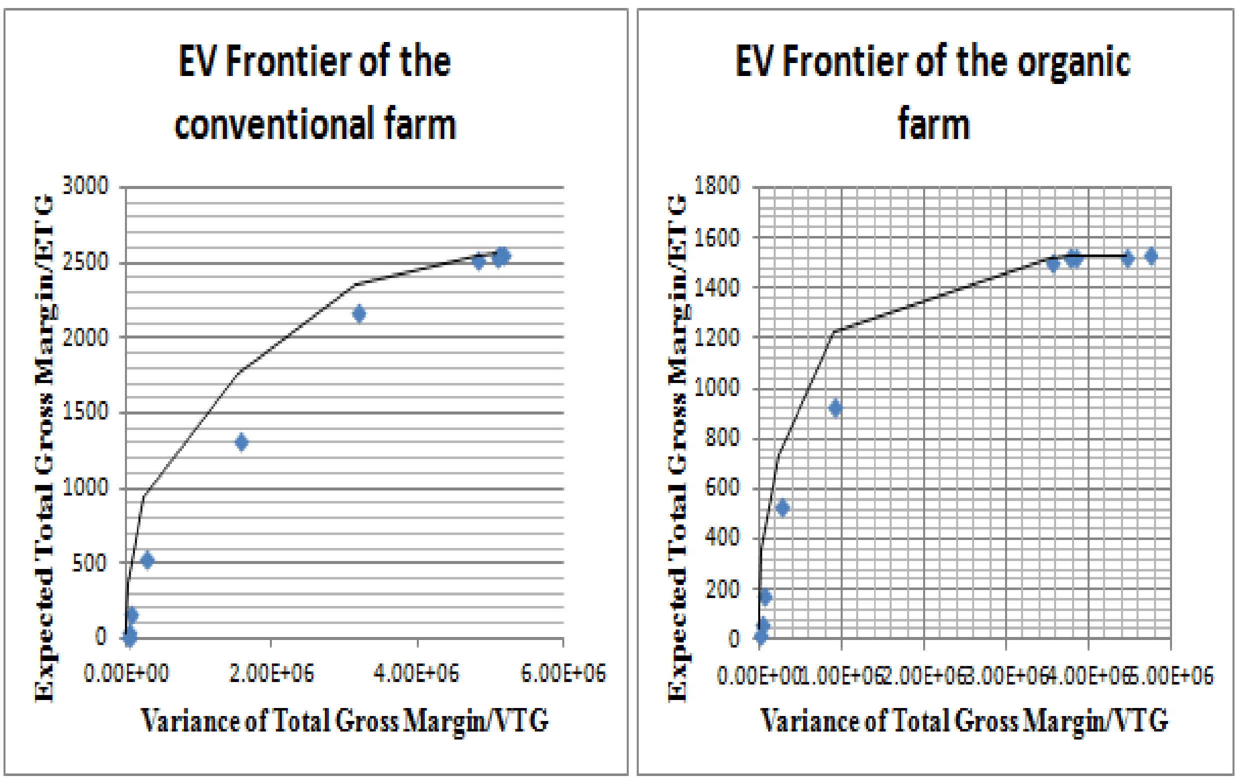
From the table above it can be seen that in the organic farm, green pepper has also the highest gross margin variance followed by tomato, cabbage, onion and eggplant. Green pepper is the riskiest in terms of its own gross margin variability in the organic farm. However, this crop is still attractive to farmers as its gross margin is negatively covariate with onion and tomato. Tomato which has the lowest yield (see table 6.6) is ranked second in terms of its gross margin's variance while cabbage occupied the third place. However, it has the highest yield (see table 5.6).

In summary, from the variance-covariance matrix analysis it could be inferred that as gross margin increases, variance increases showing that getting higher income is associated with more risk.

5.2.5.2. The Efficient frontier

For each farm, an efficient curve was derived by minimizing variance and parameterization of expected gross margin. Slope of the curve is changing with risk aversion, more the producer wants to avoid risk, steeper the curve. Those farm plan situated above the curve are not reachable and are those plans that are very risky. The farm plans located below the curve are not risky but not efficient. The efficient plans are those situated on the curve.

Figure 5.4: EV Frontier of conventional and organic farms



Source: survey data

5.2.5.3. The EV results

Table 5.12: Efficient farm Plans in the conventional and organic farm - EV solution

	CONVENTIONAL FARM									
	Farm plan1	**Farm plan2**	**Farm plan3**	**Farm plan4**	**Farm plan5**	**Farm plan6**	**Farm plan7**	**Farm plan8**	**Farm plan9**	**Farm plan10**
C1 (tl*tl2)	0.801	0.801	0.800	0.801	0.800	0.800	0.796	0.800	0.323	0.108
C2 (tl*tl2)	0.800	0.800	0.800	0.800	0.800	0.800	0.709	0.0407	0.000	0.000 0.000
C3 (tl*tl2)	0.800	0.800	0.800	0.800	0.800	0.800	0.000	0.000	0.000	0.000
C4 (tl*tl2)	0.801	0.801	0.800	0.800	0.800	0.800	0.554	0.022	0.000	0.000
C5 (tl*12)	0.800	0.800	0.800	0.800	0.800	0.800	0.000	0.000	0.000	0.000
Total area cultivated	**4.000**	**4.000**	**4.000**	**4.000**	**4.000**	**4.000**	**2.059**	**0.862**	**0.323**	**0.108**
	ORGANIC FARM									
	Farm plan1	**Farm plan2**	**Farm plan3**	**Farm plan4**	**Farm plan5**	**Farm plan6**	**Farm plan7**	**Farm plan8**	**Farm plan9**	**Farm plan10**
C6 (tl*tl2)	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.440	0.146	0.047
C7 (tl*tl2)	0.600	0.600	0.600	0.600	0.600	0.600	0.406	0.001	0.001	0.007
C8 (tl*tl2)	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.100	0.034	0.01
C9 (tl*tl2)	0.600	0.600	0.600	0.600	0.600	0.600	0.069	0.004	0.001	0.0004
C10 (tl*tl2)	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.457	0.151	0.043
Total area cultivated	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**3.000**	**2.275**	**0.998**	**0.333**	**0.111**
Risk aversion	*0.000003*	*0.000009*	*2.700000E-5*	*8.100000E-5*	*2.430000E-4*	*7.290000E-4*	*0.002*	*0.07*	*0.02*	*0.59*

Source= survey data

C1=conventional onion

C2= conventional Green pepper

C3= conventional Cabbage

C4= conventional Eggplant

C5= conventional Tomato

C6= organic onion

C7= organic Green pepper

C8= organic Cabbage

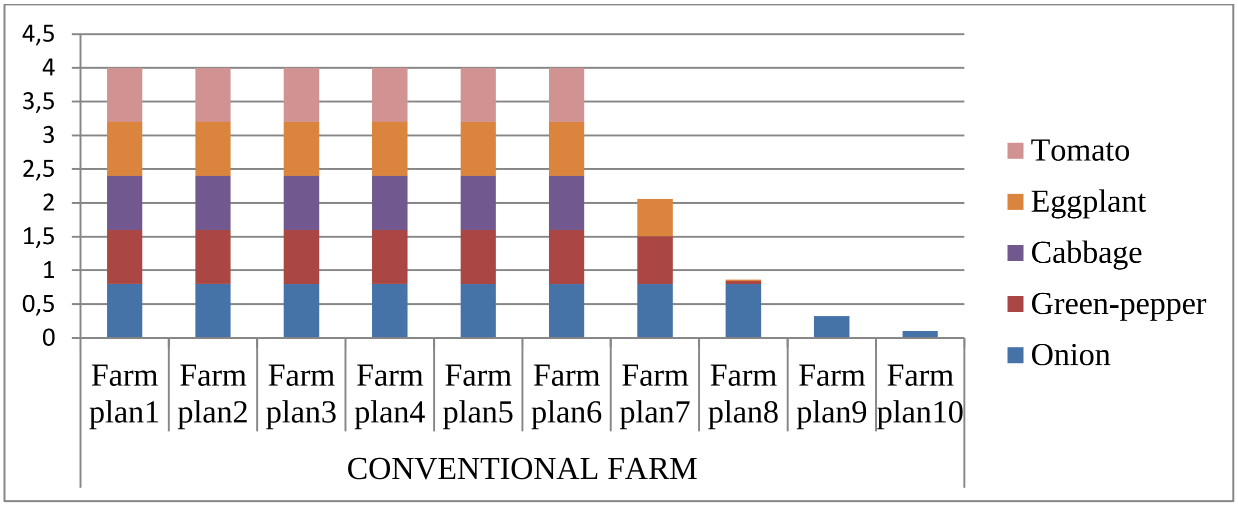
C9= organic Eggplant

C10= organic Tomato

(T1*T12)= months of the year, from January to December

The table above shows that there was more land in production in the conventional farm than in the organic farm through the year (from January to December). It also shows that from farm plan one up to farm plan six the producer in both conventional and organic farm is risk neutral. Then as the risk aversion level increases, le management strategy changes and the producer in both conventional and organic farm tend to significantly reduce the amount of land in production from farm plan seven. However, the cropland was slightly greater in the organic farm.

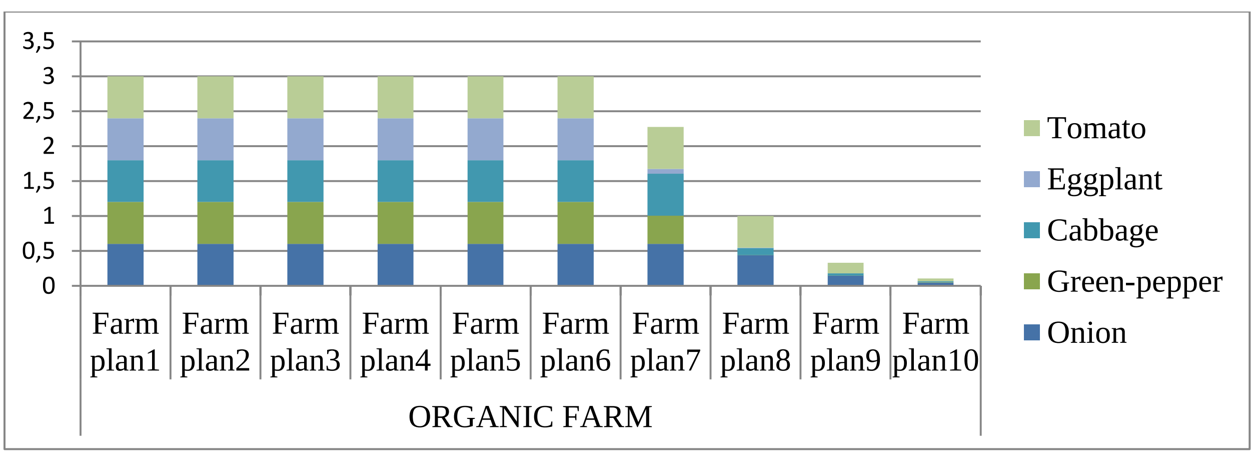
Figure 5.5: Share of farmland allocated to crops in the conventional farm



Source: survey data

The figure 5.5 above indicates that as we move from farm plan one to farm plan six, tomato is removed from the crop combination. From farm plan seven, only tree crops namely onion, green-pepper and eggplant were grown. While the acreage allocated to onion remain constant, the farm stop growing eggplant and decrease significantly the cropland allocated to green- pepper. Finally only onion is grown in a smaller portion of land at farm plans 9 and 10.

Figure 5.6: Share of farmland allocated to crops in the organic farm



Source: survey data, 2014-2015

The figure 5.6 above indicates that the number of crops grown in the organic farm was the same up to farm plan seven in contrary to the conventional farm, but with a smaller portion of land allocated to eggplant. At farm plan eight, only three crops namely onion, cabbage and tomato were grown. While onion and tomato continue to be grown up to the 10^{th} simulation, cabbage is no longer grown in farm plan nine.

Overall, the analysis of these two figures reveals that risk attitude varies from one system to another. Onion is found to be less risky in both conventional and organic farms while other crops such as tomato and cabbage are found to be more risky in the conventional farm. Therefore, it seems that when the risk aversion is high, producing under the organic farming system is more profitable than producing under the conventional farming system.

Table 5.13: Economic performances on farms, efficient solutions indicating farmers' attitude to risk

	CONVENTIONAL FARM									
	Farm plan1	**Farm plan2**	**Farm plan3**	**Farm plan4**	**Farm plan5**	**Farm plan6**	**Farm plan7**	**Farm plan8**	**Farm plan9**	**Farm plan10**
X/ha	4.000	4.000	4.000	4.000	4.000	4.000	2.059	0.862	0.323	0.108
Z/CFA	22036664	22033148	22031186	21964095	20105078	16026760	6596191	2211238	742470	247490
ETG/CFA	1837024	1836731	1836565	1830901	1675772	1336042	550216	184574	61.93	20664
VTG	5158384316	5085033212	5072137992	4811538629	3157403269	1539290169	250898647	27970642	3149594	349955
EUT	1829286	1813848	1768091	1636034	1292147	774971	275859	92817	30997	10332
α	***0.000003***	***0.000009***	***2.700000E-5***	***8.100000E-5***	***2.430000E-4***	***7.290000E-4***	***0.002***	***0.07***	***0.02***	***0.059***
	ORGANIC FARM									
	Farm plan1	**Farm plan2**	**Farm plan3**	**Farm plan4**	**Farm plan5**	**Farm plan6**	**Farm plan7**	**Farm plan8**	**Farm plan9**	**Farm plan10**
X/ha	3.000	3.000	3.000	3.000	3.000	3.000	2.275	0.998	0.333	0.111
Z/CFA	18396514	18383847	18333303	18313557	18067489	11229497	6461913	2234110	744703	248234
ETG/CFA	1533820	1532768	1528590	1526949	1506229	936166	538679	186202	62067	20689
VTG	4726212441	4442663882	3824019094	3747773726	3532515194	901112520	241177952	28380163	315335	350372
EUT	1526731	1512776	1476966	1375164	1077028	607710	274951	93101	31034	10345
α	***0.000003***	***0.000009***	***2.700000E-5***	***8.100000E-5***	***2.430000E-4***	***7.290000E-4***	***0.002***	***0.07***	***0.02***	***0.59***

Source: survey data

Z=gross margin; x=surface cultivated; ETG=expected total gross margin; VTG= variance of total gross margin; EUT=expected total utility; α=risk aversion

The table 5.13 above gives an overview of the economic performances on farms and efficient solutions indicating farmers' attitude towards risk. It shows that as the risk aversion parameter increase, the gross margin, the expected gross margin and the expected utility decrease as well as land use intensity. The producer behaves in a risk-averse way because, as its utility decrease, he stops progressively grown some crop types by reducing considerably the amount of land allocated to crop production.

Chapter 6: Conclusion, Recommendations and research perspectives

The climate change is already making adversely impact on the lives of the population particularly the poor. This is already evident in a number of ways. Consistent warming trends, decreasing precipitations and more frequent and intense extreme weather events such as droughts have been observed across West Africa in recent decades. While more attentions have been put on the impact of climate change on agriculture, today, another ongoing focus is its contribution to climate change. This is ascertained by the recent COP 21 which recommends that the continued prosperity of the food and agriculture sector will depend on the preservation of the environmental resources which are vulnerable to the adverse effects of climate change. So nowadays the world is searching solutions to move to a more sustainable way of food production in agriculture. Many types of farming systems based on sustainability have been promoted worldwide in order to adapt/ and or mitigate climate change. In Sénégal, organic farming systems have been introduced since the 80s by some NGOs. This farming system has been particularly adopted by farmers in the Niayes region where horticulture production is the main activity. The horticulture sector represents an important livelihood activity in Senegal with huge opportunity of export for fresh vegetables (green bean, tomato, etc.) to some European Union countries.

The various studies that have been carried out, generally in horticulture and particularly in vegetable farming in the Niayes mostly have focused on the conventional farming system. In addition few studies take into account issues related to climate change. Even the literature relative to the assessment of the potential of organic farming to both enhance farmers' productivity and mitigate climate change in West Africa through bio-economic models is not enough.

The present study addresses the knowledge gap mentioned above by investigating the present production and marketing system of vegetables in order to analyze the potential of organic vegetable farming system in both mitigating climate change and enhancing farmers' productivity in the Niayes region in Senegal through bio-economic models. The main findings our analysis is summarized in the following.

6.1: Summary of Results

The following conclusions were drawn from this thesis. First, vegetable production and marketing is becoming an attractive enterprise for farmers and for some marketers. Vegetable production primarily occurs in the Niayes, a geological depression with high water table that runs through the region. Vegetable production in the area meets approximately about 60 per cent of total demand in Senegal while also supplying vegetables for export to the West Africa region and to some European countries. The current vegetable production and marketing provide important economic resources to different categories of actors (producers, employees, traders, etc.). However, results about the analyse of the performance of the market through marketing margins calculations show that chain of traders are taking above 50% of the total profit margin while farmers take less than 50% of the profit margin. This share disproportion of benefits is the reflexion of poor relationship among actors. Therefore, farmers who are doing the most difficult job do not mostly benefit well from the marketing of vegetables in the study area.

Second, our research has shown that the conventional farming system is still economically more profitable than organic farming in the horticultural sector of the Niayes region in Senegal. This is mainly explained by the lower yield of the organic system and the thinness of the local market for organic food that translates into low prices of the organic products. Whereas, the equivalent carbon emission of organic horticulture is much lower than conventional horticulture. Chemical pesticides and fertilizers are greatly used by conventional farmers who sometimes use them improperly. This has engendered health risk for producers and consumers but also environmental risk with the emission of green house gases (GNGs). With the ongoing emergence of organic farming in the area, a large group of farmers are considering to adopt at least some of the organic practices. The reasons for this situation are often linked to the health risk of pesticides but also to the increasing cost of chemical inputs. Some farmers expect that adoption of organic farming will improve their access to some lucrative local niche markets or exports. In addition, we found "win-win" situation where there is a balance between economic and environmental requirements when farmers partially adopt organic farming. Our results have shed light on some of the environmental advantages of the organic farming system compared to the conventional farming system. Environmental policy regulations which are designed to benefit the society by reducing pollution have many effects. These regulations are always associated with some costs and the ways they affect productivity vary greatly and is still under debate. While some believe that the use of resources to reduce environmental pollution is extra cost that must decrease productivity, others suggest that environmental regulations promote the creation of technologies that allow farms to be more competitive and efficient (Porter Hypothesis) (Wagner, 2003).Our findings are mixed but consistent with the fact that environmental regulations can both improve environment and competitiveness.

Third, the findings of our study reveal also that producer under both system of production behave in a risk-aversion way. This is because producer's expected total gross margin is greater than the expected utility from all farm plans. However, the risk attitude and management are different from one system to another. The production of onion is found to be less risky in both systems as it is the only grown crop when risk aversion parameter is high. Moreover, the organic system offers more opportunity to grow different crops when the risk aversion parameter becomes high. The recommendations drawn from these conclusions are in the following.

6.2: Policy Recommendations

In summary, the following recommendations can be made to improve the vegetable production and marketing and to promote sustainable farming in general and in particular vegetable organic farming in the study area.

Based on the study's findings, it is recommended that the government should play an important role to facilitate and promote an efficient production and marketing system. A good starting point should be the promotion of direct marketing models through better transport and storage facilities, regular inflow of information to farmers about the prevailing wholesale market prices of commodities, and by providing market intelligence support to farmers specifically about the crop calendar and improve the availability of suitable varieties. Moreover, with an increase in the production of vegetables, the government should also provide technical support to farmers in order to help them better organize vegetable value chains and to be able to compete on the international market. Vegetable farmers on their side must better organize their cooperatives to increase their bargaining power and reduce the number of brokers involved along the chain so as to improve their margins and to better gain from the sale of their productions. Both producers and consumers would benefit from a better organized marketing system. One important entry point would be more regular opportunities to discuss marketing problems among actors that can lead to shared solutions and action plans which aimed at concrete objectives.

The first step toward the development of organic vegetable should be through consumers' awareness on agricultural knowledge focusing on the food safety system in accordance with the GAP standards. Next, for organic farming to emerge and to improve its competitiveness vs. conventional farming, appropriate investment in agro-ecological research, and the support to a more attractive local market for organic crops is required. Furthermore, the creation of manufacturing units for bio-fertilizers, bio-pesticides and waste compost are needed in order for the government to subsidy organic inputs. In addition, awareness creation and publicity through print and electronic media are necessary to promote organic farming in the country. The development of organic farming in the area will not only help producer to get more profit with a sustainable way of production but it will give new business opportunities to livestock farmers through the sale of organic manures and to some industries who are madding irrigation engines base on renewable energy such as wind and solar. In the light of the recent COP 21 that encourage countries to reduce emissions and to move toward clean development, we therefore encourage the government to support the promotion of this farming system in Niayes region and other part of the country as it can contribute to the emergence of bioeconomy in Senegal in the sense that it supports the development of production systems with reduced greenhouse gases (GHG) emissions, adapted to and mitigating the adverse effect of climate change. Specific actions are also needed to promote agricultural research and innovation to help the country to move toward a better and more sustainable economic development in the face of climate change. The "win-win" situation that we got from our simulation results has shown that with sustainable way of production farmers can improve their income and minimize the impact on the environment. Therefore, policies should encourage farming systems which are environmentally friendly. However, further studies are needed on components of sustainable intensification to see which system of production is more profitable for farmers, but also beneficial for the environment, at the regional and national levels.

Moreover, we recommend that NGOs who promote organic farming should encourage farmers to progressively adopt the system in order to help them make a balance between economic sustainability (better revenues) and environmental sustainability (less chemical fertilizers and pesticides uses). In addition, they should try to promote other farming systems (such as conservation agriculture, climate smart agriculture, etc.) which are environmentally friendly and can enhance farmer's productivity and income. This will help them in the choice of the system to promote in order to better meet farmers' needs and environmental requirements.

In terms of risk analysis, this study recommends that organic farming should be promoted since it offers more opportunity to farmers in a risky environment.

The constraints also suggest that the government should help farmers get a better access to capital as it constitutes a major limiting factor in the production and marketing of vegetables in the region. Finally, since vegetable production in the Niayes region gives great opportunities for export, the Senegalese government needs to take some concrete measures to help producers meet standards in Global Vegetable Chain (Food quality and Safety requirement).

6.3. Research perspectives

The study contributes to the knowledge regarding vegetable production and marketing in the face of climate change under conventional and organic farming systems in the Niayes region. Despite its strength, this research has limitations that future studies need to address. The results of this study which are obtained through simulation models indicate that the conventional farming system is still economically more beneficial for producers than the organic farming system. We have assumed that income volatility is due only to the price changes, while yields are kept constant over time except for the rainy season. It would be interesting to develop a model based on variable crop yield over time. To this end, future research should focus on experimental data which can provide more accurate results. Moreover, yield estimation were also made only for some major crops while examination of many varieties may lead to different results, considering the different performance each variety has under different weather patterns and soil conditions. Therefore, the results obtained here could not be generalized since calculation of variables used in our model was based on average data.

Another limitation of this study is the choice of the scale of the analysis for a specific rural community. Each rural community in the Niayes region covers a wide area of land characterized by different biophysical and socio-economic attributes. These variations within each rural community should be considered in order to help policy makers to better design appropriate interventions in the improvement of vegetable farming in the face of climate change.

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Appendices

Appendix A: Carbon Equivalent Calculations

Table: Carbon emission equivalent per crop per hectare in the conventional farm

CROPS	Urea in kg	NPK in kg	Insecticide in kg	Fungicide in kg	Poultry Manure in kg	CO2-eq in for poultry dung	CO2-eq in kg for urea	CO2-eq in kg for NPK	CO2-eq in kg for insecticide	CO2-eq in kg for fungicide	Total CO2 Emission in kg per crop
Eggplant	100	200	4	4	1000	1.6	11.19	10.71	25.245	6.045	4986
Bitter-Eggplant	100	200	4	4	1000	1.6	11.19	10.71	25.245	6.045	4986
Onion	100	100	4	4	1000	1.6	11.19	10.71	25.245	6.045	3915
Cabbage	100	200	2	6	1000	1.6	11.19	10.71	25.245	6.045	4947.5
Tomato	100	100	2	2	1000	1.6	11.19	10.71	25.245	6.045	3852.5
Green-pepper	100	100	2	2	1000	1.6	11.19	10.71	25.245	6.045	3852.5
Carrot	100	100	2	2	1000	1.6	11.19	10.71	25.245	6.045	3852.5

Table: Carbon emission equivalent per crop per hectare in the organic farm

CROPS	Cow Manure in kg	Poultry Manure in kg	Nutrient EQ/KG for poultry dung			Nutrient EQ/KG for cow dung			CO2 Emission Equivalent in kg/Nutrient in Poultry Manure			CO2 Emission Equivalent in kg/Nutrient in Cow Manure			Total CO2 Emission Equivalent/crop
									N	P_2O_5	K_2O	N	P_2O_5	K_2O	
			N %	P_2O_5 %	K_2O %	N %	P_2O_5 %	K_2O %	kg	kg	kg	kg	kg	kg	
			4.5	2.7	1.4	2	1.5	2.2	2.38	0.066	0.017	1.058	0.036	0.026	
Eggplant	750	1200							2856	79.2	20.4	793.5	27	19.5	3894.6
Bitter-Eggplant	750	1200							2856	79.2	20.4	793.5	27	19.5	3894.6
Onion	750	1000							2380	66	17	739.5	27	19.5	3348
Cabbage	750	1200							2856	79.2	20.4	739.5	27	19.5	3894.6
Tomato	750	1000							2380	66	17	739.5	27	19.5	3348
Green-pepper	750	1000							2380	66	17	739.5	27	19.5	3348
Carrot	750	1000							2380	66	17	739.5	27	19.5	3348

Source: *Own calculations following the IPCC conversion equivalent of* CO_{2-eq} *(IPCC, 2007) for chemical fertilizers and pesticides, and for manures we follow the work of Mogensen et al.,2011*

Appendix B: Simulation results from Gams

Table: Optimal land use per month in both system of production

OPTIMAL LAND USE PER MONTH									
Organic system					Conventional system				
	LOWER	LEVEL	UPPER	MARGINAL		LOWER	LEVEL	UPPER	MARGINAL
ja	-INF	0.400	1.500	.	ja	-INF	0.600	1.500	.
fe	-INF	.	1.500	.	fe	-INF	0.600	1.500	.
ma	-INF	.	1.500	.	ma	-INF	0.600	1.500	.
av	-INF	0.857	1.500	.	av	-INF	0.109	1.500	.
mi	-INF	1.257	1.500	.	mi	-INF	1.272	1.500	.
ju	-INF	1.257	1.500	.	ju	-INF	1.272	1.500	.
jl	-INF	1.257	1.500	.	jl	-INF	1.398	1.500	.
au	-INF	.	1.500	.	au	-INF	0.689	1.500	.
sp	-INF	0.343	1.500	.	sp	-INF	0.726	1.500	.
oc	-INF	0.743	1.500	.	oc	-INF	0.726	1.500	.
nv	-INF	0.743	1.500	.	nv	-INF	0.600	1.500	.
dc	-INF	0.743	1.500	.	dc	-INF	1.200	1.500	.

Table: Optimal water use per month in both system of production

OPTIMAL LAND USE PER MONTH	
Organic system	Conventional system

Organic system:

---- EQU lqw quantity of water for irrigation per month

	LOWER	LEVEL	UPPER	MARGINAL
ja	-INF	200.000	1300.000	.
fe	-INF	.	1300.000	.
ma	-INF	.	1300.000	.
av	-INF	494.286	1300.000	.
mi	-INF	706.286	1300.000	.
ju	-INF	706.286	1300.000	.
jl	-INF	580.571	1300.000	.
au	-INF	.	1300.000	.
sp	-INF	205.714	1300.000	.
oc	-INF	485.714	1300.000	.
nv	-INF	477.714	1300.000	.
dc	-INF	411.429	1300.000	.

Conventional system:

	LOWER	LEVEL	UPPER	MARGINAL
ja	-INF	318.000	1300.000	.
fe	-INF	318.000	1300.000	.
ma	-INF	258.000	1300.000	.
av	-INF	59.841	1300.000	.
mi	-INF	733.197	1300.000	.
ju	-INF	733.197	1300.000	.
jl	-INF	748.743	1300.000	.
au	-INF	247.419	1300.000	.
sp	-INF	470.364	1300.000	.
oc	-INF	470.364	1300.000	.
nv	-INF	420.000	1300.000	.
dc	-INF	678.000	1300.000	.

<u>Carbon emissions</u>

Organic

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU lqc	-INF	6356.040	25000.000	.
---- EQU lmin	.	.	+INF	EPS

lqc carbon constraint

Conventional

```
                         LOWER      LEVEL      UPPER    MARGINAL

---- EQU lqc              -INF   21046.489 25000.000      .
---- EQU lmin              .          .        +INF      EPS
```

Annual gross margin

Organic farm

```
----      506 VARIABLE RMIN.L                   =  4431600.914  REVENU MINIMUM
              VARIABLE Z.L                      =  4431600.914  gross margin FCFA
```

Conventional farm

```
----      506 VARIABLE RMIN.L                   =  8252163.722  REVENU MINIMUM
              VARIABLE Z.L                      =  8252163.722  gross margin FCFA
```

Appendix C: Efficient Farm Plans-EV solution

Efficient farm Plans in the conventional farm - EV solution

Efficient farm Plans in the conventional farm - EV solution

	Farm Plans																			
	Farm Plan 1										Farm Plan 2									
	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.109	0.362						0.110	0.110	0.110	0.109	0.359						0.111	0.111	0.111
c2		0.132	0.173		0.165	0.330						0.134	0.170		0.220	0.276				
c3			0.261	0.487	0.052	0.052							0.263	0.487		0.049				
c4	0.225					0.005		0.192	0.192	0.192	0.227							0.191	0.191	0.191
c5						0.205	0.595									0.205	0.595			
Total																				
Z	22036.664										22033.148									
ETG	1837.024										1836.731									
VTG	5.1584E+6										5.0850E+6									
EUT	1829.286										1813.848									
α	0.000003										0.000009									

	Farm Plan 3										Farm Plan 4									
	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.110	0.357						0.111	0.111	0.111	0.156	0.174						0.157	0.157	0.157
c2		0.137	0.173		0.222	0.268						0.167	0.167		0.235	0.231				
c3			0.268	0.480		0.052							0.280	0.458		0.062				
c4	0.224					0.005		0.190	0.190	0.190	0.149					0.216		0.145	0.145	0.145
c5						0.205	0.595					0.186				0.018	0.595			
Total																				
Z	22031.186										21964.094									
ETG	1836.565										1830.901									
VTG	5.0721E+6										4.8115E+6									
EUT	1768.091										1636.034									
α	2.700000E-5										8.100000E-5									

Efficient farm Plans in the conventional farm - EV solution

	Farm Plans																					
	Farm Plan 5											Farm Plan 6										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.184	0.212	0.329						0.029	0.025	0.021		0.076	0.211			0.006	0.006		0.302	0.199	
c2	0.081	0.067	0.007			0.029	0.141		0.157	0.158	0.160	0.119	0.255							0.089	0.152	0.185
c3	0.040	0.047	0.261	0.357	0.357	0.052						0.036	0.024	0.133	0.127	0.127	0.176	0.176				
c4	0.010						0.375	0.218	0.065	0.066	0.067			0.096	0.126	0.126	0.189	0.189	0.073			
c5			0.187			0.242		0.371				0.212	0.008						0.206	0.123	0.098	0.153
Total area																						
Z	20105.077											16026.761										
ETG	1675.772											1336.042										
VTG	3.1574E+6											1.5393E+6										
EUT	1292.147											774.971										
α	2.430000E-4											7.290000E-4										

Efficient farm Plans in the conventional farm - EV solution

	Farm Plan 7										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.087	0.087	0.099	0.049	0.049	0.082	0.082		0.087	0.087	0.087
c2	0.101	0.101	0.022	0.034	0.034	0.023	0.023	0.068	0.101	0.101	0.101
c3											
c4	0.079	0.079	0.020	0.021	0.021	0.016	0.016	0.063	0.079	0.079	0.079
c5											
Total area											
Z	6596.191										
ETG	1836.731										
VTG	5.0850E+6										
EUT	1813.848										
α	0.002										

	Farm Plan 8										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.113	0.113	0.049	0.045	0.045	0.048	0.048		0.113	0.113	0.113
c2	0.003	0.003		0.001	0.001	3.7445E-4	3.7445E-4	0.023	0.003	0.003	0.003
c3											
c4				6.1746E-4	6.1746E-4						
c5											
Total area											
Z	2211.238										
ETG	550.216										
VTG	2.5090E+5										
EUT	275.859										
α	0.007										

Efficient farm Plans in the organic farm - EV solution

	Farm Plans									
	Farm Plan 1									
	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.017	0.533						0.017	0.017	0.017
C7			0.277	0.050	0.067	0.206				
C8				0.319		0.281				
C9										
C10					0.254	0.073	0.273			
Total										
Z	17626.065									
ETG	1469.413									
VTG	4.2116E+6									
EUT	1463.095									
α	0.000003									

	Farm Plan 2									
	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.017	0.533						0.017	0.017	0.017
C7			0.220	0.107	0.140	0.132				
C8				0.298		0.302				
C9	0.227									
C10			0.028		0.173	0.100	0.299			
Total										
Z	17612.868									
ETG	1468.325									
VTG	3.7305E+6									
EUT	1451.538									
α	0.000009									

	Farm Plan 3									
	T1	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.017	0.533						0.017	0.017	0.017
C7			0.195	0.131	0.166	0.108				
C8				0.275		0.325				
C9										
C10			0.060		0.139	0.092	0.309			
Total										
Z	17608.263									
ETG	1467.947									
VTG	3.6752E+6									

	Farm Plan 4										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.013	0.013	0.533						0.013	0.013	0.013
C7				0.155	0.155	0.155	0.136				
C8				0.140	0.140	0.143	0.176				
C9											
C10				0.027	0.027	0.025	0.073	0.448			
Total											
Z	17538.866										
ETG	1462.221										
VTG	3.4995E+6										

	Farm Plans										
	Farm Plan 9										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.040	0.040	0.016	0.016	0.016	0.016	0.016	0.040	0.040	0.040	0.040
c2											
c3											
c4											
c5											
Total area											
Z	742.470										
ETG	61.993										
VTG	3149.594										
EUT	30.997										
α	0.020										

	Farm Plan 10										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
c1	0.013	0.013	0.005	0.005	0.005	0.005	0.005	0.013	0.013	0.013	0.013
c2											
c3											
c4											
c5											
Total area											
Z	247.490										
ETG	20.664										
VTG	349.955										
EUT	10.332										
α	0.059										

	Farm Plans																					
	Farm Plan 9											Farm Plan 10										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.022	0.022	0.009	0.06	0.06			0.017	0.022	0.022	0.022	0.007	0.007	0.003	0.002	0.002			0.006	0.007	0.007	0.007
C7						1.6711E-4	1.6711E-4										5.5703E-5	5.5703E-5				
C8				0.007	0.007	0.01	0.01								0.002	0.002	0.003	0.003				
C9																						
C10	0.022	0.022	0.009	0.006	0.006	0.005	0.005	0.011	0.022	0.022	0.022	0.007	0.007	0.003	0.002	0.002	0.002	0.002	0.004	0.007	0.007	0.007
Total area																						
Z	744.700											248.233										
ETG	62.067											20.689										
VTG	3153.350											350.372										
EUT	31.034											10.345										
α	0.020											0.059										

EUT	1418.331	1320.493
α	2.700000E-5	8.100000E-5

	Farm Plans																					
	Farm Plan 5											Farm Plan 6										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.013	0.013	0.533						0.013	0.013	0.013	0.094	0.094	0.131						0.094	0.094	0.094
C7				0.15	0.15	0.15	0.15					0.076	0.076		0.055	0.055	0.055	0.055		0.076	0.076	0.076
C8				0.149	0.149	0.151	0.151								0.119	0.119	0.119	0.119	0.124			
C9																						
C10								0.6				0.03	0.03	0.205					0.244	0.03	0.03	0.03
Total area																						
Z	17463.467											10822.727										
ETG	1456.000											902.399										
VTG	3.3759E+6											8.4530E+5										
EUT	1045.822											594.289										
α	2.430000E-4											7.290000E-4										

	Farm Plans																					
	Farm Plan 7											Farm Plan 8										
	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12	T1	T2	T3	T4	T5	T6	T7	T9	T10	T11	T12
C6	0.128	0.128	0.069						0.128	0.128	0.019	0.066	0.066	0.026	0.018	0.018			0.051	0.066	0.066	0.066
C7	0.064	0.064	0.014	0.009	0.009	0.009	0.009	0.025	0.064	0.064	0.078						5.0133E-4	5.0133E-4				
C8				0.083	0.083	0.083	0.083	0.104			0.165				0.020	0.020	0.030	0.030				
C9																						
C10	0.097	0.097	0.063	0.014	0.014	0.014	0.014	0.040	0.097	0.097	0.056	0.066	0.066	0.027	0.019	0.019	0.019	0.019	0.032	0.066	0.066	0.066
Total area																						
Z	6458.388											2234.100										
ETG	538.333											186.202										
VTG	2.4088E+5											28380.149										
EUT	274.929											93.101										
α	0.002											0.07										

Appendix D: Questionnaires

QUESTIONNAIRE

This study is conducted under WASCAL Graduate Program on Climate Change Economics at UCAD-FASEG. We are studying the effectiveness of organic farming in enhancing farmers' productivity and mitigating climate change.It is necessary to obtain information from farmers like you and therefore your help in answering these questions is highly appreciated. This information is being collected for academic purposes only, and there are no personal benefits or risks to your participation. The interview will take about one hour. You are free to not answer any question with which you are not comfortable.

IDENTIFICATION

- Name of Enumerator
- Date and name of the study zone
- Status of farmer (Bio Or Conventional)

Beginning time of interview:

End time of interview :

I. BACKGROUND CARACTERISTICS OF FARMER

Name of farmer

CARCTERISTICS	CODE	RESPONSE
1. Name		
2. Gender	1=male 2=female	
3. Age		
4. Marital status	1=married; 2=divorced; 3=widowed; 4=single	
5. What do you represent for this household?	1=head of the household; 2=wife of the head of the household; 3=others (specify)	
6. What is your ethnical group?	1=wolof; 2=sérère; 3=peulh; 4=diola; 5=others (specify)	
7. What is the highest level of schooling you have attained?	0=none; 1=some primary education; 3=college; 4=secondary school; 5=university; 6=others (specify)	
8. What is your social status?	1=retired; 2=salaried; 3=housewife; 4=village chief; 5=village council; 6=mason; 7=carpenter; 8=farmer; 9=others (specify)	
9. How many people live in your household?		
10. What are your main economic activities?	1=rainfed agriculture; 2=livestock keeping; 3=trade; 4=gardening; 5= arboriculture; 5=agro-food processing; 6=others (specify)	

II. LAND OWNERSHIP AND UTILISATION

CARACTERISTICS	CODE	RESPONSE
11. What is the size of your land?	1=1 ha; 2=2 to 5 ha; 3=6 to 10; 4=11 to 15ha; 5=16 to 20ha; 6=others (specify)	
12. What is the type of land ownership?	1=ancestral land; 2=; 3=private property with title deed; 4=leasehold; 5=others (specify)	
13. What is the total land under cultivation?		
14. What is the total land under pasture?		
15. What is the total land not exploited?		
16. What type of agriculture do you practice?	1=rainfed agriculture; 2=	
17. What type of cattle do you keep?	1=sheep; 2=goats; 3=cows; 4=horses; 5=donkeys; 6=poultry; 7=a bit of everything sited above; 8=others (specify)	
18. What is the distance from nearest market?	1=less than one kilometer; 2=2 to 3 km; 3=4 to 6km; 4=7 to 9 km; 5=10km and above	
19. What is the main means of transport for farm products to the market?	1=lorry; 2=car; 3=cart; 4=donkeys; 5=others (specify)	
20. What are sources of extension services?	1=none; 2=government; 3=NGO; 4=private; 4=others (specify)	
21. What is the frequency of extension services?	1=weekly; 2=monthly	

III. Yields and Revenue Structures:

Type of Crops	Surface cultivated in hectare	Yields in kg	Yields for marketing in kg	Price of Crops	Total Revenue

IV. **Field Operations :**

Type of Crops	Number of days required to perform the task		Total number of persons required to perform the task	How many persons from the family?	How many persons do you hire?	Le cost of temporary hiring labor
	Cleaning					
	Plant nursery					
	Land preparation					
	Sowing/planting					
	1st fertilizer application					
	Water spray					
	2nd fertilizer application					
	Arrosage					
	1st weeding					
	Pesticides application					
	2nd weeding					
	harvesting					

V. **PESTICIEDES ET FERTILIZERS USED**

Type of Crops	Type of fertilizer	Quantity used for 1ha in kg	Price	Phytosanitary products	Quantity used for 1ha	price
	Urea			Fungicide		
	NPK			Pesticide		
	Poultry manure			Herbicide		
	Cow manure			Nime		
	compost					
	Urea			Fungicide		
	NPK					
	Poultry manure			Pesticide		
	Cow manure			Herbicide		
	Compost			Nime		

VI. USE OF FUEL FOR MOTOR-PUMPING

Type of Crops	Type of fuel use	Number of liter required to spray water on 1ha	Price of 1liter	Time spend for water spray per season

VII. CALANDAR

		J	F	M	A	M	J	J	A	S	O	N	D
	Cleaning												
	Plant nursery												
	Land Preparation												
	Sowing/Planting												
	1st fertilizer application												
	Second fertilizer application												
	Water spray												
	1st weeding												
	1st Pesticides application												
	2nd weeding												
	2nd Pesticide application												
	Harvesting												

VIII. ACCESS TO SEED

How do you get seed?	1. Buying 2. Government 3. others	
How much do you spend for seed of each type of crop per season?	Carrot	
	Egg-plant	
	Bitter-eggplant	
	Tomato	
	Cabbage	
	Onion	
	Green Pepper	
How do you plough your land?		
Do you practice inter-cropping and rotation in your farm?		

QUESTIONNAIRE FOR TRADERS

This study is conducted under Wascal graduate program on Climate Change Economics at UCAD-FASEG. We are studying marketing channels and performance of organic and conventional vegetables in the Niayes. It is necessary to obtain information from traders like you and therefore your help in answering these questions is highly appreciated. This information is being collected for academic purpose only and there are no personal benefits or risk to your participation. The interview will take about 30 minutes. You are free to not answer any question with which you are not comfortable.

IDENTIFICATION

- First and Last Name of interviewer

Date of the survey and name of the village

- **Type of Agent**
  (Collector or « bana-bana », Wholesaler, Retailer)

Beginning of interview:

End of interview:

1

I. BACKGROUND FEATURES OF RESPONDENT

1. Name and surname

QUESTION	CODE	REPONSE
2. Gender	1=male 0=female	
3. Age of respondent	Number of years or year of birth	
4. Marital Status	1=married ; 2=divorced ; 3=widowed ; 4=Single	
5. What is your ethnical group?	1=Peulh ; 2=Sérère ; 3=wolof ; 4=Toucouleur ; 5=other (specify)	
6. What is the highest level of study you have attained?	1=none ; 2= some primary education; 3=college ; 4=secondary school ; 5=university ; 6=other (specify)	
7. What is your social status?	1=retired ; 2=salaried ; 3=housewife 4=village chief ; 5=village council ; 6=mason ; 7=carpenter; 8=farmer ; 9=other (specify)	
8. What are your main economic activities? *(many answers are possible)*	1=rain fed agriculture ; 2=livestock keeping ; 3=trade; 4=vegetable gardening ; 5=agro-food processing ; 9=other (specify)	
9. For how long have you being in the trading of vegetables?	1=less than 5years; 2=5-10 years ; 3=10-15years ; 4=more than 15 years	

II. INFORMATION RELATED TO THE COMERCIAL ACTIVITY

Question	Code	Answer
10. How did you get the capital to start your business activity?		
11. Do you pay a tax for this activity?	1=yes ; 2=no	
12. If yes, how much per month or per day?		
13. Where do you buy the vegetables that you sell?	1=farm gate ; 2=market village ; 3=other (precise)	
14. Where do you resell them?		
15. How do you get information about prices?	1=at the market place ; 2= from neighbors/friends ; 3=other (precise)	
16. What type of costs do you face in doing this business?		
17. At what period during year do you get the best prices?		
18. Do you know about organic vegetables ?	1=yes ; 2=no	
19. If yes, do you buy these organic vegetables and sell them?		
20. What are the advantages of these vegetables compared to conventional vegetables?		
21. What type of problem do you face in doing this business?		

III. INFORMATION RELATED TO THE PRICE AND QUANTITY OF VEGETABLES

VEGETABLE TYPE	QUANTITEY IN KG OU BAG	PRICE1	PRICE2	PRICE3

Price 1=cold season; Price 2=dry season; Price 3=rainy season

QUESTIONNAIRE FOR HOUSEHOLD

This study is conducted under Wascal graduate program on Climate Change Economics at UCAD-FASEG. We are studying marketing channels and performance of organic and conventional vegetables in the Niayes. It is necessary to obtain information from household members like you and therefore your help in answering these questions is highly appreciated. This information is being collected for academic purpose only and there are no personal benefits or risk to your participation. The interview will take about 30 minutes. You are free to not answer any question with which you are not comfortable.

INDENTIFICATION

- First and last name of interviewer
- Membership group of respondent (Rural or Urban)

Beginning of interview:

- Date of the interview and name of the village

End of interview :

I. BACKGROUND FEATURES OF RESPONDENT

1. Name and surname

QUESTION	CODE	REPONSE
2. Gender	1=male 0=female	
3. Age of respondent	Number of years or year of birth	
4. Marital Status	1=married ; 2=divorced ; 3=widowed ; 4=Single	
5. What is your ethnical group?	1=Peulh ; 2=Sérère ; 3=Wolof ; 4=Toucouleur ; 5=other (specify)	
6. What is the highest level of study you have attained?	1=none ; 2= some primary education ; 3=college ; 4=secondary school ; 5=university ; 6=other (specify)	
7. What is your social status?	1=retired ; 2=salaried ; 3=housewife 4=village chief ; 5=village council ; 6=mason ; 7=carpenter; 8=farmer ; 9=other (specify)	
8. What are your main economic activities? *(many answers are possible)*	1=rain fed agriculture ; 2=livestock keeping ; 3=trade; 4=vegetable gardening ; 5=agro-food processing ; 9=other (specify)	

II. IFORMATION RELATED TO VEGETABLE PURCHASING

Question	Code	Answer
9. Do you eat vegetables ?	1=yes ; 2=no	
10. If yes, where do you buy the vegetables that you consume?		
11. Are the vegetables available during all period of the year?	1=yes ; 2=no	
12. Si oui, durant quelle période les prix sont élevés ?		
13. Do you know organic vegetables?	1=yes ; 2=no	
14. If yes, do you use to buy them and where?		
15. What are the advantages of these vegetables compared to conventional vegetables?		

III. INFORMATION RELATED TO THE PRICE AND QUANTITY OF VEGETABLES

VEGETABLE TYPE	QUANTITEY IN KG	PRICE1	PRICE2	PRICE3

Price 1=cold season; Price 2=dry season; Price 3=rainy season

Appendix E: Field Work Pictures

Picture1: collecting point of organic vegetables

Picture2: Nursery of green pepper and well in a farmer field

Pictures by author

Picture 3: Personal interview with farmers

Picture 4: Focus group discussions

Picture: Natural solution preparation for treatment in an organic farm

Picture: Garden landscape and irrigation system