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YEAR: 2023 **ORDER N^0:**

DRIVERS OF LAND DEGRADATION IN TRAYS ECOSYSTEMS AS MODULATED UNDER A CHANGING CLIMATE: A CASE STUDY OF IVORY COAST

PhD. THESIS

Presented and defended publicly on the **05th April 2023** for the obtention of the grade of Doctor ès Economics Sciences

BY

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Ph.D. RESEARCH DISSERTATION

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DECLARATION

*I, **ANGAMAN Kadio Valere Rodolphe**, declare that the current thesis submitted for the degree of PhD in Economics (option, Climate Change Economics) at UCAD (Université Cheikh Anta Diop) Dakar/ Senegal for the Graduate Study Program of WASCAL (West African Science Service Center on Climate Change and Adapted Land Use) is entirely my work and has not been submitted before wholly or in parts at any other university.*

Parts of this thesis have been presented during conferences.

I am also responsible for any error in thinking and omission that could be parts of this dissertation.

DEDICATION

To

God for making it possible;

All those who supported my education until this level;

Father and Mother ANGAMAN,

Also;

My uncles FATTO Goly Nicolas and AMANE Koffi Rene;

My girlfriend Souleymane Awa;

Professor Fatou Gueye-Lefevre, who passed away when she was the WASCAL Senegal Director

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At the end of this work, I have to express my gratitude to all those who, through their cooperation and dedication, have contributed to the production of this work which crowns our efforts and marks one more step in my scientific journey.

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ACRONYMS & ABBREVIATIONS

CEC: Cation Exchange Capacity

COP: Conference of Parties

ESA: Environmental Sensitive Area

FAOSTAT: Food and Agriculture Organization Statistics

GDP*:* Gross Domestic Product

Ha: Hectares

IPCC: Intergovernmental Panel on Climate Change

IUCN: ***International Union for Conservation of Nature***

LD: Land Degradation

LDN: Land Degradation Neutrality

LULCC: Land Use and Land Cover Change

MINEDD: Ministère de l'Environnement et du Développement Durable

MINSEDD : Ministère de la Salubrité, de l'Environnement et du Développement Durable

NDVI: Normalized Difference Vegetation Index

PANLCD : Programme d'Action National de Lutte Contre la Désertification

PNAE: Plan National d'Action Environnementale

REDD+: Reduction of Emission from Deforestation and Forest Degradation

REEA: Recensement des Exploitants et Exploitation Agricole

RGPH: Recensement General de Population et de l'Habitat

ROC: Receiver Operating Characteristics

SLM: Sustainable Land Management

SODEMI: SOciété pour le DÉveloppement MInier de la Côte d'Ivoire

SOM: Soil Organic Matter

UNCBD: United Nations Convention on Biological Diversity

UNCCD: *United Nations Convention to Combat Desertification*

UNFCCC: United Nations Framework Convention on Climate Change

USLE: Universal Soil Loss Equation

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ABSTRACT

This dissertation aims to analyse the economic impact of land degradation and how to reverse its negative trend on farmers' well-being in the trays ecosystem in Cote d'Ivoire under changing climate. Specifically, this thesis aims to i) identify the key drivers of land degradation; ii) evaluate the reduction of net farmers' income due to land degradation; and iii) identify the determinants of simultaneous adoption of sustainable land management practices in the trays ecosystem. The study used quantitative techniques with primary data obtained from farmers through questionnaires. The logistic model, Instrumental variable (Two-stage least square), and multivariate probit regression are used to deal with our specific objectives. From the results, climate variables such as temperature and precipitation play an important role in land degradation and the simultaneous adoption of sustainable land management practices. At the same time, soil organic matter reduction is responsible for the economic impact of land degradation. Considering the importance of agricultural sector in GDP formation and the fact that land degradation is responsible for many issues like food insecurity, migration, conflict, etc., in the country, it is primordial to reverse its negative trend by adopting sustainable land management practices to increase the population's well-being, particularly those of the farmers. To reverse this negative trend of land degradation, it is recommended to improve farm management skills, allow access to credit and make information available on SLM practices by the government, non-governmental organizations, and community leaders in charge of combatting land degradation and climate change.

Keywords: Drivers, land degradation, economic impact, sustainable land management, Ivory Coast

RESUME

Cette thèse vise à analyser l'impact économique de la dégradation des terres et comment renverser sa tendance négative sur le bien-être des agriculteurs dans l'écosystème des plateaux en Côte d'Ivoire sous le changement climatique. Plus précisément, elle vise à i) identifier les principaux facteurs de dégradation des terres ; ii) évaluer la réduction du revenu net des agriculteurs due à la dégradation des terres ; et iii) identifier les déterminants de l'adoption simultanée de pratiques de gestion durable des terres dans l'écosystème des plateaux. Cette thèse a utilisé des techniques quantitatives avec des données primaires obtenues auprès des agriculteurs au moyen de questionnaires. Le modèle logistique, la variable instrumentale (Doubles Moindres Carrés), et la régression probit multivariée ont été utilisés pour traiter nos objectifs spécifiques. D'après les résultats, les variables climatiques telles que la température et les précipitations jouent un rôle important dans la dégradation des terres et l'adoption simultanée de pratiques durables de gestion des terres. De même, la réduction des matières organiques du sol est responsable de l'impact économique de la dégradation des terres. Considérant l'importance du secteur agricole dans la formation du PIB et le fait que la dégradation des terres est responsable de nombreux problèmes comme l'insécurité alimentaire, les migrations, les conflits, etc., dans le pays, il est primordial de renverser la tendance négative de la dégradation des terres en adoptant des pratiques durables de gestion des terres pour accroître le bien-être de la population, en particulier celui des agriculteurs. Pour renverser cette tendance négative de la dégradation des terres, il est recommandé d'améliorer les compétences en gestion agricole, de permettre l'accès au crédit et de rendre l'information sur les pratiques de gestion durable des terres accessible par le gouvernement, les organisations non gouvernementales, et les responsables communautaires en charge de la lutte contre la dégradation des terres et le changement climatique.

Mots clés : Facteurs, dégradation des terres, impact économique, gestion durable des terres, Côte d'Ivoire

GENERAL INTRODUCTION

Background

Everywhere in the world, people use land. It is a vital resource allowing food production, animal feed, fiber, wood, and energy. Also, it provides the primary basis for human livelihood and well-being, food supply, freshwater, many other ecosystem functions, and essential human services, such as preserving biodiversity and facilitating the water system's natural management (IPCC, 2020a). Land constitutes a source and a greenhouse gas sink (Watson et al., 1992) simultaneously, and it is essential in exchanging energy and aerosols between the land surface and the atmosphere. Also, through urbanization, its utilization permits the road for displacement, building houses for habitat, institutional and recreational infrastructure, etc.

According to IPCC (2020), more than 70 % of the global land surface is affected by human land use. Its sound management may protect and maximize the services that it provides to society. Conversely, its poor control can cause several issues to the community, such as land degradation, which leads to agricultural productivity loss, the release of greenhouse gas in the atmosphere, the loss of biodiversity, and otherwise, the loss of ecosystem services. The overall ecosystem service loss attributed to land degradation is estimated to be between US$ 6.3 and 10.6 trillion annually (IUCN, 2015a).

According to Cerretelli et al. (2018), land degradation is one of the significant issues facing developing countries due to soil depletion. UNCCD estimates that land degradation affects two-thirds of developing countries' productive land (Vrščaj & Ammann, 2013). Indeed, for several decades, developing countries that encompass almost all countries in Africa have observed a reduction in their agricultural productivity. This decline in agricultural productivity caused by land degradation on the continent is estimated to be between 2-40% (Eswaran et al., 2001).

Among these countries facing land degradation, Ivory Coast has been the most affected by land degradation. Indeed, in Ivory Coast, land degradation is a severe problem because of its significant dependence on natural resources. The agricultural sector still dominates the structure of the economy. Its contribution to GDP formation is 23%, employs more than 2/3 of the active population, and generates 66% of export revenues (World Bank, 2018). Its population of around 29,389,150 million habitants (INS, 2021) exerts pressure on land through urbanization and food production. The population is identified as one of the significant causes of land degradation (Meseret, 2016). Also, climate change, another global issue, exacerbates land degradation (Kumar & Jyoti Das, 2014) in the country. It is caused by human activities and is manifested in the country by a change in precipitation patterns, a decrease in annual heights, and an increase in average yearly temperature (Brou et al., 2005). These issues have consequences on the population's welfare and the economy; above all, the economy is still dominated by agriculture. The implications of both phenomena are many. These are low income, food insecurity, migration, conflicts, scarcity of arable land, desertification, etc.

The country has developed a National Plan Combating Land Degradation (PANLCD), aligned with the 10-Years Framework (2008-2018) of the United Nations Convention to Combat Desertification (MINSEDD[1], 2017) to reverse the strong trend of land degradation and mitigate the effect of climate change.

In addition, the country has enacted laws and strategies to combat land degradation. He joined the UNCCD-initiated “Land Degradation Neutrality (LDN)” program. Apart from the National Plan Combating Land Degradation and enacting laws and strategies to combat land degradation, several international and regional conventions, agreements, and commitments to protecting the environment and natural resources have been ratified by Ivory Coast. The country clearly expresses its commitment to protecting the environment and fighting against land degradation through these acts. These include the Rio Conventions (UNCDB, UNCCD, and UNFCCC).

Despite many agreements and policies put in place, land degradation continues to grow in Ivory Coast. Deforestation, extensive and intensive agriculture, mining activity, urbanization, wood energy supply, infrastructure creation, and overgrazing lead to land degradation (MINSEDD, 2017). There are two types of land degradation in Ivory Coast: physical, chemical and biological. Physical degradation is the primary cause of water erosion, and its modalities are compaction, mass taking, bulk take, crusting, modification of soil water regime, and soil erosion. Chemical and biological degradation are due to the influence of three natural phenomena, aggravated by inappropriate agricultural practices due exclusively to human activities (Brabant, 1992). The natural phenomena include loss of nutrients and humus, salinization, and acidification. In addition

[1] It is the institution in charge of the protection of environment and sustainable development in Ivory Coast

to these phenomena, another one exclusively attributed to human activities is pollution which can take various types.

Problem statement

Land degradation and climate change are interconnected phenomena that negatively affect the environment and the population's well-being (Siva Kumar & Ndiang'ui, 2007a). They accelerate drought, flood, coastal erosion, rising sea level, migration, conflict, food insecurity, soil erosion, etc., significantly impacting the population's well-being. They cause a reduction in agricultural productivity worldwide, particularly in Ivory Coast. This reduction contributes to increasing poverty or vulnerability of people because, as mentioned above, two-thirds of the active population in Cote d'Ivoire depend on agriculture (FAO, 2019). Indeed, the scarcity of rainfall combined with the high temperature, which has resulted in the shortening of the rainy season, poses with acuity the problem of crop calibration because agriculture in the country is essentially rainy agriculture (MINEDD[2], 2014). Consequently, farmers harvest low yields, reducing their income and welfare.

Côte d'Ivoire is a developing country with around 29 million inhabitants and contains 318,000 square kilometers of land. However, rapid population growth, urbanization, and unreasonable human utilization led to the degradation of its lands, accelerating climate change. Also, the loss of more than 80% of its natural forests in 50 years (IUCN, 2016) releases carbon dioxide into the atmosphere, which contributes to changes in the climate and leads to the quick degradation of lands and environmental degradation in the country. The forest loss and biodiversity are more pronounced in the western and southwestern parts because these parts are more arable.

In Ivory Coast, social inequality and poverty also play an essential role in the degradation of the environment, which plays a vital role in land degradation. Poor people over-exploit their almost depleted resources to survive. For example, poor people use firewood as the only affordable energy source for cooking and heating. This fact leads to the loss of the forest and biodiversity, a powerful means to store carbon dioxide.

Land degradation is not the same in different ecosystems (Salvati & Zitti, 2009a; Wei et al., 2020). How land is degraded in the mountain differs from how it is degraded in coastal zones or trays.

[2] Ministry of Environment and the Sustainable Development (MEDD) an English.

Also, the speed some lands are degrading varies from one ecosystem to another, and land management is not the same in all parts of the country.

Land degradation is more pronounced in the trays ecosystem because, since independence, this ecosystem was reputed for producing cocoa and coffee. The population was concentrated more than in dry land (northern part) to benefit from the service of this ecosystem. The people living in the trays ecosystem are mostly poor; they draw income from land and exert pressure on it through several activities such as farming, breeding, etc. Most of the population are farmers who are specialized in producing food crops, cash crops, and coal manufacturers. This fact helps Nelson et al. (2006) to say that population and land management play an important role in land degradation.

Land degradation is a big issue in Ivory Coast, where the agricultural sector dominates the economic structure. Since its independence, the country has suffered from land degradation. It is one contributor to climate change and one factor that can help mitigate it if it is well managed. From 2000 to 2010, the situation worsened with a degradation rate of 11% of the territory, around 3.547.093 ha. The lands presenting a net productivity decrease are around 1.607.454 ha, and the carbon stock has decreased by 444.384 tons (MINSEDD, 2017). Indeed, if the land is degraded, it can release the carbon stored in soils. The ability of lands to store carbon depends on the climate, soil type, crop or vegetation cover, and land management practices (Schahczenski & Hill, 2009).

However, to cope with land degradation, enhance land use and mitigate the adverse effects of climate change, there is a need to understand better the drivers of land degradation in Ivory Coast in tray ecosystem. This leads us to ask some research questions.

Research Questions, Objectives, and Hypotheses

Research Questions

For this thesis, the main research question is:

- **What is the economic impact of land degradation in the trays ecosystem under a changing climate in Ivory Coast?**

The sub-research questions are:

- What are the keys drivers of land degradation in the trays ecosystem in Ivory Coast?

- What is the economic impact of land degradation on the farmer's income in the trays ecosystem?
- What are the determinants of the simultaneous adoption of sustainable land management practices?

Objectives

To answer the questions asked, objectives have been set up. The main goal of this dissertation is **to analyze the economic impact of land degradation in the trays ecosystem under a changing climate in Ivory Coast.**

As specifics objectives, this study wants to:

- Identify the key drivers of land degradation in the trays ecosystem.
- Evaluate the reduction of net farmers' income due to land degradation in the trays ecosystem.
- Identify the determinants of simultaneous adoption of sustainable land management practices in the trays ecosystem.

Research Hypotheses

The general hypothesis of this study is that **climate variables play an essential role in land degradation.**

The specific hypothesis on which this study is focused are:

- The increasing temperature and/or decreasing precipitation lead to land degradation.
- The reduction of soil organic matter is responsible for the reduction of the net income of farmers.
- The decrease in precipitation determines the adoption of simultaneous SLM practices.

Methodology Brief

To tackle the objectives of this dissertation, quantitative and qualitative techniques are employed using primary data. The logit regression model is used to identify the key drivers of land degradation in tray ecosystems for the first specific objective. The choice of this model is due to the data available and the nature of the assessment (O. K. Kirui & Mirzabaev, 2015).

Concerning the second specific objective, two-stage least square is used to deal with it. The use of Two-stage least squares with instrumental variables is to overcome several potential endogeneity issues in estimating causal links between land degradation and farmer income.

For the last specific objective, the multivariate probit model (MVP) is used to solve it. MVP is chosen because farmers consider a set of practices and choose the practices that maximise their expected utility. Therefore adoption decision is multivariate, and attempting a univariate modeling approach will exclude useful information contained in the interdependent and simultaneous adoption decisions (O. K. Kirui & Mirzabaev, 2015).

Shortcomings

This dissertation, like many scientific works, has some shortcomings. These shortcomings vary from time, techniques, and data availability. Indeed, for instance, given the time frame constraints, the results of the interviews are based on primary data collected in only one region in the trays ecosystem selected for this dissertation. Given that different regions have different climate exposure, ethnic groups, and cultures, future studies need to focus on the overall ecosystems to better quantify the impact of land degradation in the country. Another shortcoming of this study is that land degradation and climate change are dynamic processes, so the full impact would be better assessed using time-series data on farmers and breeders.

Organization

This dissertation is structured as follows: After this general introduction, the first chapter presents the link between climate change and land degradation. In this chapter, the concepts of climate change and land degradation, as well as the different types of land degradation, these causes, and consequences, will be reviewed. The second chapter focuses on the factors which drive land degradation in trays ecosystems and will help us to identify this ecosystem's key drivers of land degradation. Chapter three, for its part, deals with the economic impact of land degradation on farmers' income. This chapter evaluates the income loss by farmers due to land degradation in the trays ecosystem under a changing climate. Chapter four presents the determinants of the simultaneous adoption of sustainable land management practices in the trays ecosystem under a changing climate. After chapter four, the general conclusion follows.

1.0 CHAPTER ONE: CLIMATE CHANGE AND LAND DEGRADATION NEXUS

1.1 Introduction

Climate change and land degradation are two phenomena commonly associated with environmental degradation through losses of vegetation cover, ecosystem productivity, and soil resources crucial to rural livelihoods and the provision of ecosystem services. They have intensified global agricultural production and food security challenges for several decades (Diamond, 2005). Tackling these challenges is imperative for building sustainable farming systems that feed the growing world population (Webb et al., 2017a).

Land degradation and climate change are interrelated in the measure where climate change causes land degradation on the one hand, and land degradation causes climate change on the other. This relationship is the result of biophysical and human factors. Land degradation reduces plant water availability by raising runoff and decreasing the soil's water-holding capacity through erosion, organic matter loss, and soil texture deterioration (Herrick et al., 2013). It exacerbates climate change by reducing its power to store carbon dioxide through vegetation cover and also because it releases carbon dioxide into the atmosphere.

Conversely, climate change also influences land degradation. Its influence on land degradation is because the scarcity of precipitation and the high temperature destroys land's organic matter production, rapidly leading to land degradation. Also, a low organic matter content of land leads to bad aggregation and low aggregate stability, resulting in high erosion by wind and water, which leads to land degradation (Siva Kumar & Ndiang'ui, 2007a). Land degradation can be exacerbated by climate change through the increase in temperature, low precipitation patterns, increased evapotranspiration rates, changes in biodiversity, etc. (Webb et al., 2017a).

Land degradation reduces the benefits that ecosystems provide to society. Consequently, it jeopardizes food security and reduces the welfare of the people, especially farmers. When land is degraded, it can release greenhouse gases such as carbon dioxide or nitrous into the atmosphere (IUCN, 2015b). This fact ranks it among the most significant contributors to climate change.

Land degradation can also be caused by land use and natural phenomena such as volcanic eruptions, heavy rainfall, drought, etc. It can manifest in diverse ways across agroecological systems. For instance, land degradation in the forest is affected by canopy cover and biomass reduction. In the croplands, land degradation is manifested by soil erosion and nutrient reduction, while salinization, acidification, and compaction are manifested in dryland.

According to Webb et al., (2017), land degradation is estimated to affect more than 25% of the global land area. It is a big issue facing the world with several drawbacks, such as reduced crop production, increased poverty rate, migration, etc. To curb land degradation, sustainable land management practices are needed.

1.2 Concepts of climate change and land degradation

Studying the nexus between climate change and land degradation is highly debatable, probably because of differences in defining concepts and methods. To have the best understanding of the concepts used for studying the nexus between climate changes and land degradation, some concepts which encompass climate change will be defined first, and some of land degradation will also be defined after.

1.2.1 Climate change concepts

Several important concepts of climate change are defined in this thesis to have the best understanding of these concepts. These are:

1.2.1.1 Weather

Weather is often confused with climate. It is the atmosphere's behavior at a given period and our daily or weekly observation of climate variables (Tomlinson et al., 2013). In other words, the weather is a daily condition in the atmosphere at a given period. Weather represents atmospheric events over a short time, such as in a minute, an hour, or a day, and varies from place to place. Weather and climate are related. Indeed, to monitor climate, the average daily weather is used.

1.2.1.2 Climate

Climate is the statistical probability of the occurrence of various states of the atmosphere over a given region during a given period. It involves the systematic observation, recording, and processing of various elements such as temperature, rainfall, pressure, humidity, wind, sunshine, and cloud (Tomlinson et al., 2013). Climate, more closely, is defined as mean weather. The average and variability of the relevant quantities in terms of statistical description ranges from months to years. According to the World Meteorological Organization, the period required for averaging these variables is 30 years. When scientists talk about climate, they often refer not only to dynamic weather variables but also to a broader set of variables that describe the ocean's state (subsurface ocean temperature) and some variables which describe ice sheets and glaciers (Werndl, 2014).

1.2.1.3 Climate change

The United Nations Framework Convention on Climate Change (UNFCCC), in Article 1, defines climate change as a change in mean weather attributed directly or indirectly to human activity. This change in mean weather alters the composition of the global atmosphere, adding to natural climate variability observed over comparable periods. It is a change in the state of the climate that is identified by average changes or variability in climate properties over a generally long period. Climate change results from human activities such as land use, fossil burning, forest exploitation, urbanization, etc. However, it may be due to internal or external natural processes such as volcanic eruptions, modulations of solar cycles, etc.

The main characteristics of climate change are the increase in the global average temperature, changes in cloud cover and precipitation over land, melting of ice caps and glaciers, reduced snow cover, increase in the ocean temperatures, and ocean acidity due to seawater absorbing heat and carbon dioxide from the atmosphere (UNFCCC, 2007).

1.2.1.4 Climate variability

According to IPCC (2012), climate variability refers to variations in the mean state and other climate statistics (such as standard deviations, etc.) at all spatial and temporal scales beyond individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or natural or anthropogenic external forcing (external variability) variations. The term "climate variability" is often used to refer to differences in climate statistics over a given period (e.g., a month, season, or year) compared to long-term statistics for the same calendar period.

1.2.1.5 Greenhouse gas

Greenhouse gases are gases that retain heat in the atmosphere. More broadly, greenhouse gases are gases that absorb in the atmosphere heat from the sun and reduce the amount of heat that escapes into space. They are responsible for the high temperature in the atmosphere, which permits global warming. These gases are carbon dioxide, methane, nitrous oxide, and fluorinated. They represent, respectively, 80%, 10%, 7% and 3% of the atmosphere (US EPA[3], 2015). The fluorinated gases are more powerful and last a long time in the atmosphere contributing to global warming like the others. These gases can remain in the atmosphere for different periods, ranging from a few years to thousands of years.

1.2.2 Land degradation concepts

The following concepts are those frequently used when the study is focused on land degradation. These are:

1.2.2.1 Land

Land is defined as the terrestrial portion of the biosphere that comprises the natural resources (soil, near-surface air, vegetation, other biotas, and water), the ecological processes, topography, human settlements, and infrastructure that operate within that system (IPCC, 2020b). Also, the land is perceived as a physical entity in terms of topography and spatial nature. It plays an essential role between the land surface and its atmosphere by exchanging energy, water, and aerosols. It is a powerful means to store and relax greenhouse gases in the atmosphere. Land is a renewable and finite resource; however, the resources vary over time and according to the frequency of use and management conditions.

1.2.2.2 Soil

Soil is the material that helps plants to grow and provides physical support, water, and nutrients (Nortcliff et al., 2006). It is composed of water, air, and organic matter. The soil formation includes five factors: Climate, Organisms, Topography, Parent Material, and Time. On the topsoil surface, Soil Organic Matter (SOM) is more abundant than below ground, called subsoil; this makes topsoil more fertile. Soil plays an essential role in the daily life of living things. Indeed, soil sequesters carbon, purifies water, absorbs and retains pollutants, regulates flooding, and allows nutrient cycling. It is an important environment for plant growth and supports a large part of the animal and human activity.

1.2.2.3 Land degradation

Many definitions are given to define land degradation in the literature. According to IPCC (2019), land degradation is defined as a negative trend in land conditions caused by direct or indirect

[3] United States Environmental Protection Agency. See more https://www.epa.gov/ghgemissions/overview-greenhouse-gases

human-induced processes, including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following aspects: biological productivity, ecological integrity or value to humans. For D'Odorico & Ravi (2016), land degradation reduces land's ability to provide ecosystem services. It results in lousy management of the natural capital as soils, water, vegetation, etc., by humans and sometimes by natural forces such as drought, volcanic eruption, flood, runoff, etc., that affect land through periodic stresses from extreme and persistent climate events (Z. Li et al., 2015). It can start through the hydrological system in the climate change context (IPCC, 2019b). According to Nachtergaele et al. (2010), land degradation is the reduction in land capacity to provide ecosystem goods and services over time. This definition is one of the more comprehensive definitions given by some authors on this topic. Land degradation during significant rainfall events intensifies flooding and erosion of soil. The infiltration reduction makes gullies channel water more rapidly to rivers, magnifying peak flows. Land degradation can be measured by the organic matter present in the soil. The less the soil has organic matter, less it is declared degraded. A soil with an organic matter comprised between 3 and 6 is considered fertile. The organic matter in soil depends on the organic material input, the rate of the decomposition of these inputs and the rate at which soil organic matter is mineralized, climate, and soil texture (Johnston et al., 2009). It can also be measured by the net primary productivity (NPP)[4] change and deviation from the standard indicator of land degradation used (Z. G. Bai et al., 2008). However, a negative NPP does not mean land degradation, nor does a positive NPP mean an improvement in the land. As a proxy, normalized difference vegetation index (NDVI) is used from remote sensing images.

1.2.2.4 Land use

Land use refers to the total arrangements, activities, and inputs undertaken in a particular land cover type (a set of human actions). Land use is used for the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation) (IPCC, 2012). It is perceived as a regular human intervention to meet the needs of nature (Vink, 1975). People use land to suit their needs in life. All forms of human intervention concerning land to respond to the material and spiritual needs are referred to as land use (Somantri & Nandi, 2018). It is also called

[4] Net primary productivity is how much carbon dioxide vegetation takes in during photosynthesis minus how much carbon dioxide the plants release during respiration (metabolizing sugars and starches for energy).

human activity on specific land areas to meet human needs. The association of land cover and land management gives land use. Land use differs from one location to another and exists in different forms, such as recreational, transport, agricultural, residential and commercial. However, land-use patterns may have different effects on flora and fauna. As adverse effects, vegetation cover and deforestation may disappear and threaten animal and vegetal species. Concerning the positive effects, proper land use can protect agricultural land, forests, water quality, open spaces, and wildlife habitat while increasing property values and human health.

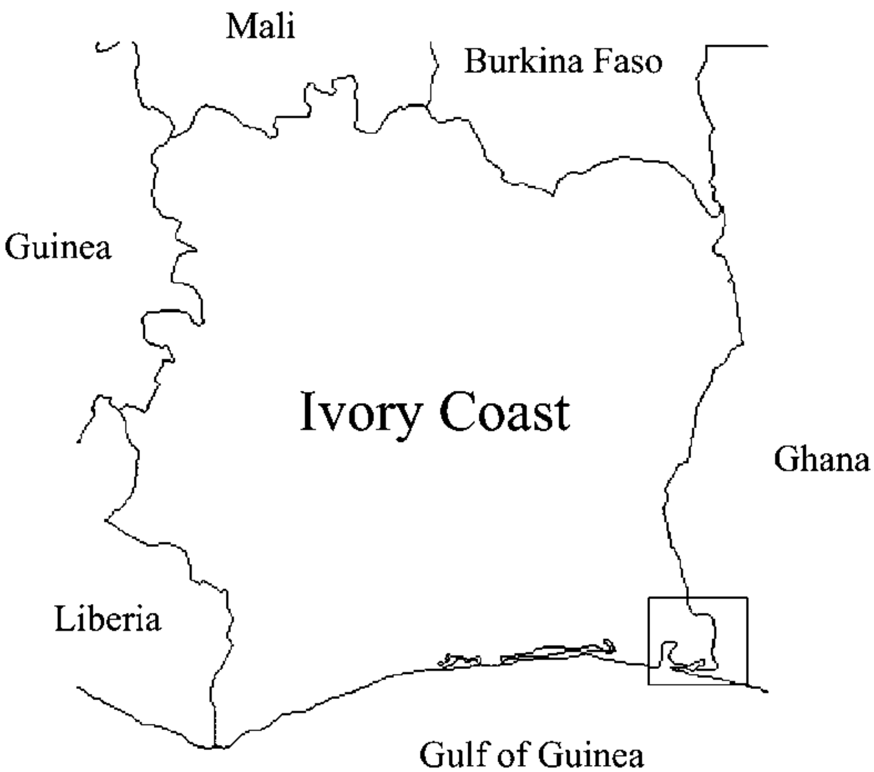
1.2.2.5 Sustainable land management (SLM)

Sustainable land management is the use and management of the resources of land, such as soil, water, animals, and plants, for the reproduction of goods to meet the growing human needs while ensuring the long-term productive potential of these resources and the preservation of environmental functions (Alemu, 2016). For TerrAfrica (2005), sustainable land management is “the adoption of land-use systems that through appropriate management practices enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources.” Sustainable land management is an instrument that can alleviate land degradation, recover degraded land and allow the optimal use of land resources to benefit the present and future generations. When it is seen as an integral aspect of land use planning, it helps to improve soil moisture and increase nutrient cycling, resulting in production and productivity. It is directly related to all activities. However, the link between sustainable land management and agriculture is very important; in the measure, the latter is directly related to land. Many countries, mainly developing countries, have economies focused on agriculture; they need to adopt sustainable land management to improve their agricultural productivity and care for their environment.

1.3 General Characteristics of Ivory Coast

Located in West Africa, Cote d’Ivoire is a country of 322 462 km² (MEDD, 2014). Its population is estimated at 29,389,150 million inhabitants (INS, 2021). Mali and Burkina Faso border it in the North, Ghana in the East, the Atlantic Ocean and the Guinea Gulf in the South and Liberia and Guinea in the West (see figure 1).

Figure 1: Ivory Coast and its border countries



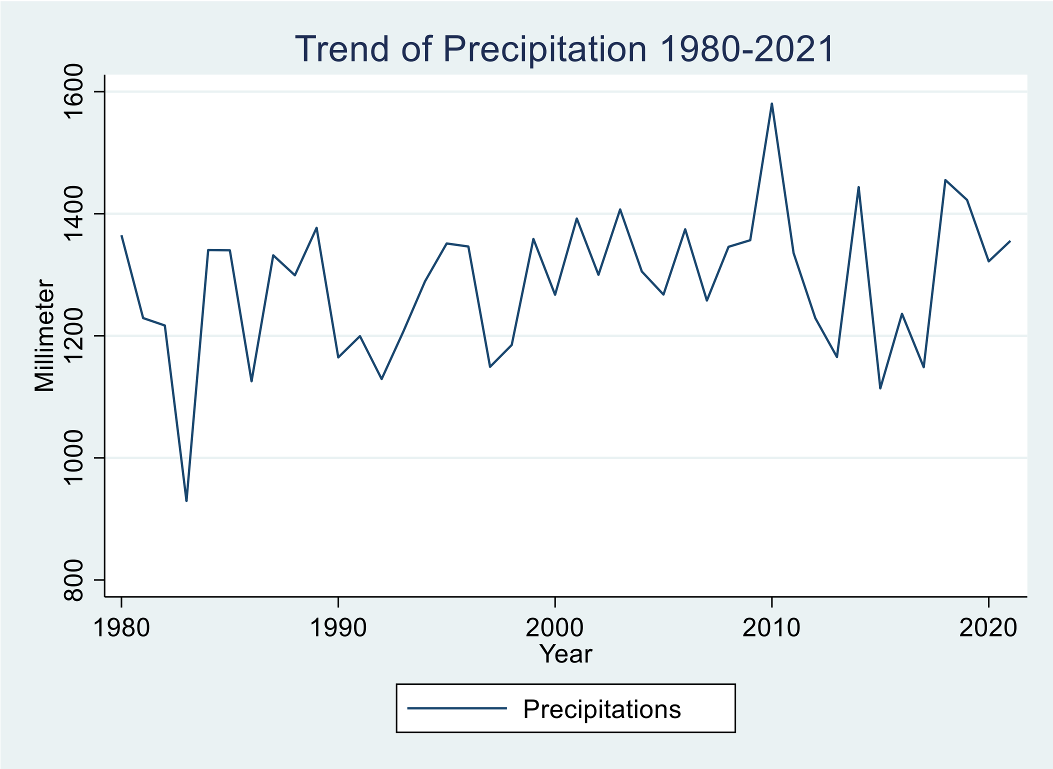
Source: William Scott Mcgraw (2005).

1.3.1 Climate in Ivory Coast

Ivory Coast has two climatic regions typical of the two main types of landscapes: the savannah and clear forest in the northern part; dense and wet forest in the southern part, which includes a dry and rainy season. Two rainy seasons characterize the southern climate. The most intense and the longest has a maximum in June; the shortest is centered in October and separated by the small "dry season" of August-September. The large dry season has an average of 3-5 months, including December, January, and February.

The northern climate of Ivory Coast has only one rainy season, with maximum intensity in august. The only dry season lasts from 6 to 8 months. Since the 1980s, precipitations are no longer regular and begin timidly and intermittently from February to May by marking stops during July to end in October (N. Nadège et al., 2016). Figure 2 presents the evolution of precipitation means over the national territory from 1980 to 2021. From 1980 to 1983, the precipitations drastically decreased to evolve into sawtooth until 2010. The precipitations decreased from 2010 to 2013 and then increased in 2014. After 2014 the evolution was made in sawtooth to achieve the second lowest value (1113.93 mm) of precipitation recording from 1980 to 2021.

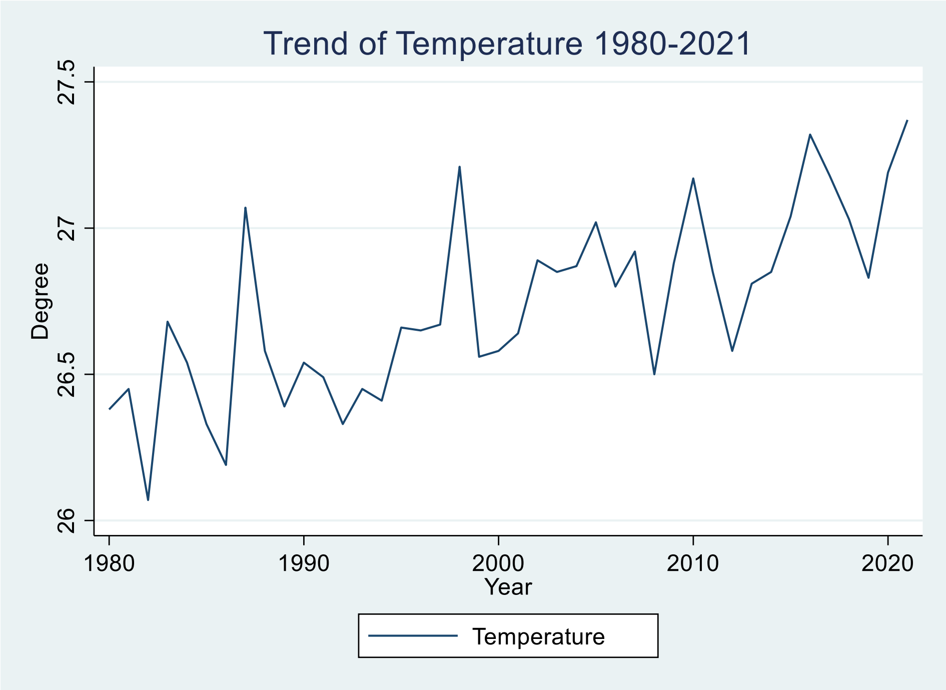
Figure 2: Precipitation Trend 1980-2021



Source: author compilation using data from world development indicators

Figure 3 presents the evolution of temperature means over the national territory from 1980 to 2021. The figure depicts an increasing trend in the temperature with sometimes a decrease. The evolution was made in sawtooth with an upward trend. The year 2021 was when the temperature peaked (27.37 °C) after 1998 when the temperature was 27.21°C.

Figure 3: Temperature Trend 1980-2021



Source: Author using data from world development indicators

1.3.2 Vegetation

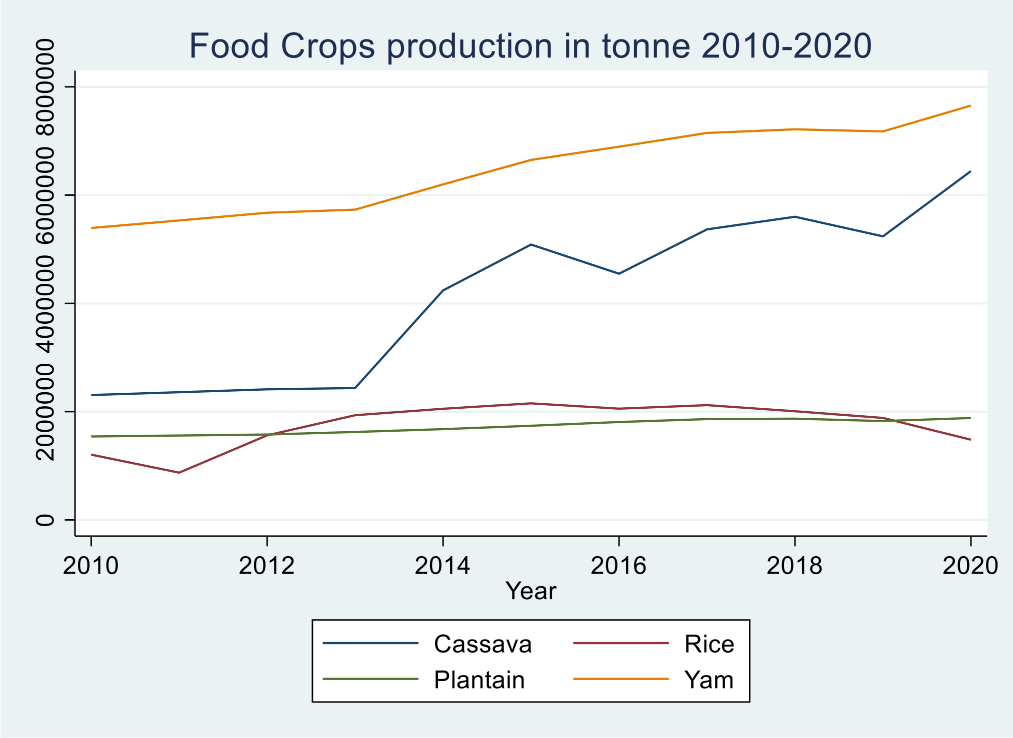
The Ivorian territory is subdivided into two Domains. These two areas are the Guinean domain, in the south, covered with dense humid forest, and the Sudanese Domain, in the North, where savannahs are the main source of vegetation. The Guinean Domain occupies broadband of 350 km and covers a little less than 50% of the territory. It is made up of four sectors which are: the umbrophile sector occupied by dense humid evergreen forests; the mesophilic sector constituted of semi-deciduous wet, dense forests; the mountainous area occupied by dense forests and mountain savannahs; and the coastal area composed of coastal savannas, pre-lagoon savannas, and mangroves.

Concerning the Sudanese Domain, it consists of two sectors which are: the Sub-Sudanese sector, made up of clear forests and savannas, with a few islands of dense forests concerning 3/4 of the entire Sudanese Domain, and the Sudanese sector, made up of clear forests and different types of savannas, occupies 1/4 of the domain (MINEDD, 2014).

1.3.3 Agricultural production systems

The economic development of Ivory Coast is focused on agriculture which accounts for around 23 percent of its total GDP and over two-thirds of all exports (World Bank, 2019b). Two cropping systems are adopted in Ivory Coast. These are the food crop system and cash crop system. The food crop system encompasses yam, rice, plantain, cassava, etc. These crops are the main crops produced in the country. In terms of production, yam is the most produced food crop, accounting for around 4.7 percent of agricultural GDP formation. Rice's contribution is estimated to be 1.72 percent of agricultural GDP and is produced under three production systems: rainfed, lowland, and irrigated. Concerning plantain, it is essentially produced for the domestic market. Cassava is grown almost in all areas of the country, but more production is obtained in the forest region. Figure 4 shows the evolution of the production of the crops quoted above from 2010 to 2020.

Figure 4: Food crops Production 2010-2020



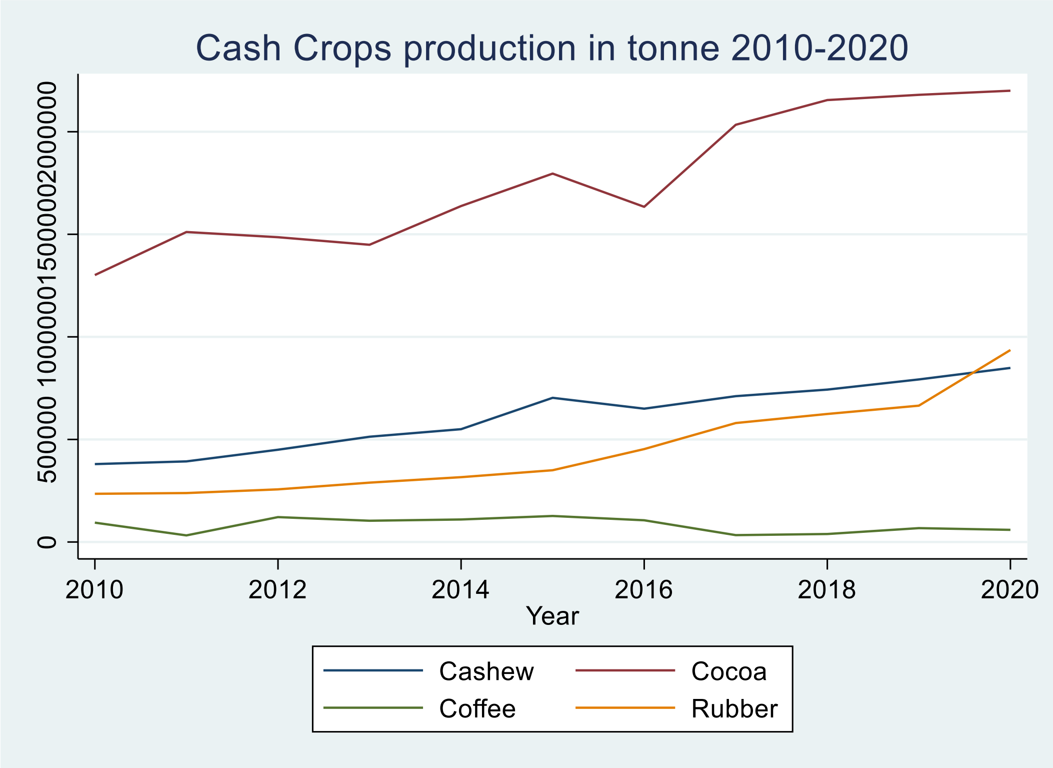
Source: Author using data from FAOSTAT

The figure shows that yam has the highest production, followed by cassava, rice, and plantain. The yam production increased from 2010 to 2018, decreased in 2019, and increased again in 2020 to achieve a total value of 7654617 tonnes. Cassava production increased from 2010 to 2015, with a slight decrease in 2016. After 2016, the production increased and peaked in 2018 with an amount estimated at 866452 tonnes, then decreased in 2019. In 2020, the production achieved its pic with a total output of 1165250 tonnes. Regarding rice, after a decrease in 2011, its production increased from 2012 to 2015. In 2016, its production decreased slightly to increase in 2017. From 2017 to 2020, a downward trend in production is observed. Concerning the plantain, its production is almost stable, slightly increasing from 2010 to 2018. In 2019, the production decreased, then increased in 2020.

The cash crop system encompasses cocoa, coffee, cashew nut, rubber, palm tree, etc. Cocoa is produced in the forest for about 5 percent of agricultural GDP. The country is the world's first largest cocoa producer, accounting for 44 percent of exportation. Cashew contributes around 1.3% of agricultural GDP formation. In 2015, Ivory Coast was the world's top exporter of cashew nuts, with 702,510 tonnes. In 2018, its production was estimated at 761,000 tons, and its part in the exportation is estimated at 4 percent (FAO & ICRISAT, 2018).

For coffee, the country is the third producer behind Ethiopia and Uganda, with a total production estimated at 67697 tonnes. Its part in the exportation is estimated at 3 percent. Figure 5 presents the evolution of some cash crop production from 2010 to 2020. Cocoa had the highest production from 2010 to 2020, followed by cashew, rubber, and coffee, as figure 5 shows. From 2010 to 2016, cocoa evolved in sawtooth to experience growth from 2016 until 2020. Cashew and rubber experienced a gradual evolution from 2010 to 2020. Between 2012 and 2016, the production of coffee remained almost stable, finally known with a decrease in 2017. From 2017 to 2020, the production increased.

Figure 5: Cash crops Production 2010-2020



Source: Author using data from FAOSTAT

With climate change and the increasing land degradation, the production of some crops has increased on the one hand and decreased; on the other hand. It is maybe due to some practices adopted by farmers that consist of practicing the extensive culture, and others use the new generation of seeds for some culture to improve their production. Tables 1 and 2 show respectively the yields and the harvested areas of some crops quoted above.

Some crops like cocoa, coffee, rubber, and cassava are facing a decrease in their yields as the year's pass. Cashew faced a downward trend in its yields from 2010 to 2016, while an upward trend was facing between 2018 to 2020 (Table 1). Rice, for its part, apart from 2010, has a yield which increases slightly yearly. The yield of yam has three known phases. From 2010 to 2012, an upward trend was observed, while a downward was observed from 2012 to 2019. After 2019, the yield increased. Similarly, plantain's yield faced three phases: from 2010 to 2012, a downward trend in its yield was observed; from 2013 to 2019, an upward trend was observed to decrease in 2020.

Table 1: Cash and food crop yields from 2010 to 2020

	Cash crops				Food crops			
Year	Cashew	Cocoa	Coffee	Rubber	Cassava	Plantain	Rice	Yam
2010	4057	5711	2140	14045	66000	37700	30546	65000
2011	4078	5628	1979	16555	66900	37500	22993	66300
2012	4119	5411	1657	16525	65900	37000	23526	66997
2013	4158	5305	1504	16489	65339	37435	24545	65820
2014	4183	5310	1434	16401	64731	38081	24962	63473
2015	4197	5194	1330	16235	63731	38370	25509	62008
2016	4254	4949	1096	16241	62744	38134	25587	60216
2017	4227	4803	956	16196	61981	38122	26051	58731
2018	4126	4677	829	16152	61219	38113	26526	57245
2019	4143	4564	710	16108	60456	38105	26996	55760
2020	4173	4607	785	16169	55298	37530	28505	63767

Source: Author using data from FAOSTAT

Table 2 shows increased harvested areas for rubber, yam, and plantain from 2010 to 2020. The crops like cashew, cocoa, cassava, and rice have their harvested area, which has increased during the whole period with a slight decrease in 2016. Coffee is the crop the most unstable in terms of area harvested.

Table 2: Cash and food crops areas harvested from 2010 to 2020

	Cash crops				Food crops			
Year	Cashew	Cocoa	Coffee	Rubber	Cassava	Plantain	Rice	Yam
2010	936740	2278786	441066	167356	349521	408905	394868	829595
2011	963643	2685121	163206	144195	352618	415789	379694	834369
2012	1092446	2746080	732998	155286	366065	426228	663920	847010
2013	1234559	2731411	689759	175610	372903	433913	788011	870817
2014	1314771	3084498	766335	192751	654908	440317	822667	976571
2015	1675000	3458163	954793	215583	798201	453217	844023	1072438
2016	1527877	3301756	966868	278931	724854	474375	803131	1145043
2017	1681943	4234606	351374	358104	865908	488428	813790	1217083
2018	1800944	4606820	471778	386449	914810	490803	756623	1260447
2019	1913073	4776874	953972	412649	866452	479242	697886	1287087
2020	2033886	4774875	756447	578923	1165250	501667	519620	1200405

Source: Author using data from FAOSTAT

1.3.4 Land use in Ivory Coast

Arable land in Ivory Coast is around 21 million hectares (ha). It represents 64% of the country's total area. From its independence to today, Ivory Coast has lost almost all its forest cover. Its forest cover has declined from 16 million to 2 million hectares (FAO & ICRISAT, 2018). The factors that lead to this deforestation are wood energy, such as charcoal used by around 47 percent of the urban population, expansion of agriculture, bush fires, and tree exploitation. In 2016, land use was re-distributed as follows: forest 33 percent, arable land 9 percent, permanent crops 14 percent, permanent meadows 41 percent, and others 3 percent (FAO & ICRISAT, 2018).

1.4 Land degradation in Ivory Coast

Since its independence, Ivory Coast has undergone severe land degradation. As part of the LDN[5] process, the country has established an overview of its degraded land and vegetation loss based on national and international data provided by the UNCCD. This section focuses on the overview of land degradation, vegetation loss, and the policies to address them.

1.4.1 Overview of land degradation

From 2000 to 2010, there was a degradation rate of 11% of the territory or 3,547,093 hectares of soil. Specifically, 1,956,800 hectares were affected by negative transformations. Land with a decrease in net productivity is about 1,607,454 hectares. Forest cover has been reduced by 4.21%, corresponding to a loss of 1,360,000 hectares. Savannah shrubs have been reduced by 596,800 ha. Wetlands and water bodies have decreased by 9,600 hectares. The increase in cultivated land area by 5.87% over the reference period confirms these changes. A decrease in productivity affects one million six hundred seven thousand five hundred hectares (1,607,500 ha) or 5% of the land (MINSEDD, 2017). The amount of carbon sequestered by forest areas converted to cropland was 1,791,738 tons in 2000. This quantity decreased to achieve 1,347,354 tons in 2010, corresponding to a loss of 444,384 tons of carbon during this decade attributed to land degradation or biodiversity loss.

1.4.2 Policy and commitment to address land degradation and vegetation loss

The exceptional agricultural expansion has made Ivory Coast a middle-income country and has made it the world's largest cocoa producer and the fourth coffee producer for years (MINEDD, 2014). However, it has destroyed the vegetal cover, singularly the dense rainforest, whose more fertile soils are particularly sought by the farmers. The excessive exploitation of forest species, the collection of energy wood, mining, and the misuse of land increase the pressure on the vegetation cover. To reverse the strong trend of land degradation, the country has developed a National Plan to Combat Land Degradation (PANLCD), aligned with the ten-year framework (2008 – 2018) of the United Nations Convention to Combat Desertification (UNCCD).

[5] Land Degradation Neutrality to know more : https://www.unccd.int/actions/achieving-land-degradation-neutrality

In 1988, the government adopted Forest Director Plan to stop the reduction of its vegetal cover. Having noted the weakness of the results compared to the ambitions of the Forest Director Plan in 1996, the Government adopted in August 1999 a new policy framework for the forest. To achieve the objectives of this forest policy, a 14 years Forest Management Framework Program has been adopted. This program aimed to improve the timber industries' potentiality and reforestation. In 1995, Ivory Coast defined its National Environmental Action Plan (PNAE) for 1996-2010, focusing on biodiversity protection (MINEDD, 2014). Also, several international and regional conventions, agreements, and commitments on environmental protection and natural resources have been ratified by Ivory Coast. These include the Rio Conventions: UNCDB, UNCCD, and UNFCCC (MINSEDD, 2017). In 2011, to generate international support to address deforestation, which is one driver of land degradation, the government embarked on the national REDD+ process (FCPF, ONU-REDD, 2014). On COP 21, during the Paris agreement in 2015, the country's authorities submitted their intended Nationally Determined Contribution to the United Nations Framework Convention on Climate Change (UNFCCC). This contribution includes a set of REDD+ actions that consider sustainable forest management, increased forest cover, and zero deforestation in agriculture. In addition, the Ivorian president, during his speech in 2014 to the United Nations, endorsed the New York declaration on forests. He has committed to producing cocoa with zero deforestation and restoring the forest cover to 20% of the national territory by 2030.

1.5 Different types of land degradation

The degradation that land undergoes can be classified into two types. These are physical, chemical and biological nature of degradation (Brabant, 1992; Von Braun et al., 2013).

1.5.1 Chemical and biological degradation

Three natural phenomena cause chemical and biological degradation, and a fourth is purely anthropogenic, mainly based on pollution and inappropriate agricultural practices. They include salinization, acidification, loss of nutrients and humus, and pollution.

1.5.1.1 Loss of nutrients and humus

Loss of nutrients and humus occurs in all lands but is accentuated in those with low to medium natural fertility. Indeed, according to Brabant (1992), after the harvest, the nutrients elements used by the plant for their growth are not replaced by mineral fertilizer or organic amendments. Because of population growth, land is continuously used, which exhausts land nutrients that are affected by yield or harvesting. This type of degradation remains low whether the farmers practice natural fallow. The continued use of land without nutrients contributes to an inevitable drop in production. Loss of humus after clearing natural vegetation leads to the same results. Thus, the productivity of equatorial forest land cleared decreases rapidly after five years of cultivation. This degradation is most often associated with water erosion in savannah lands. Moreover, the collected eroded soil still contains high organic matter bound to clay and nutrients.

1.5.1.2 Salinization

Salinization is defined as the accumulation of soluble amounts of salts of sodium, magnesium, and calcium in the soil (R. J. A. Jones & Montanarella, 2003). According to Baartman et al. (2007), it is a natural process resulting from high levels of salt in the soil from landscape features that allow salts to become mobile. It occurs in arid and semi-arid lands with low rainfall, abundant and intense evaporation. Water from the ground evaporates while the salt precipitates and concentrates on it little by little. The salt accumulated in the soil becomes toxic for the plants and makes land unusable. Salinization can be caused by human-induced factors such as the intensive exploitation of soils formed on material containing salts, pollution of overexploited aquifers by intrusions of marine water, and irrigation by water overloaded with salts. This form of salinization caused by human activities is called secondary salinization (Baartman et al., 2007). Land use, land management, land degradation, and farming systems are the most human factors leading to salinization. Also, the natural process due to salt accumulation in groundwater is another cause of soil salinization called "primary salinization." The most influential natural factors leading to salinization are land cover, topography, vegetation type, climate, and soil parent material. Salinization significantly reduces soil quality and vegetation and induces desertification effects. Salinization does not allow for the permeability of deep soil layers, making it impossible to use the land for cultivation. It leads to loss of soil fertility because of toxic effects of great salt content and biodiversity. It depreciates the value of land, damages the infrastructure of water supply and damages the infrastructure transport from shallow saline groundwater (Montanarella, 2007).

1.5.1.3 Acidification

Soil with a pH below five is considered degraded by acidification (Brabant, 1992). Acidification is when the soil's pH decreases over time, and agricultural production accelerates it. According to

Bolan et al.(2005), soil acidification is a natural process due to some plants and human activities. Acidification may result from overexploitation in continuous cultivation, excess acidifying fertilizer such as ammonia sulfate, and exploitation of specific soils such as mangrove. Acidification promotes nutrient leaching and soil fertility loss (R. J. A. Jones & Montanarella, 2003). In managed ecosystems, soil acidification is caused during the transformation and carbon cycle of nitrogen and Sulphur and fertilizer reactions by releasing H^+ protons.

1.5.1.4 Pollution

Pollution of soil is caused by human activities, mainly industrial, agro-industrial, urban, and sometimes agricultural. Examples include pollution by pesticides in rural areas, heavy metals, acid rain, chemical, and radioactive waste. Pollution can have various origins. These are:

- Industrial pollution

Industrial pollution is assimilated to pollution which is directly linked to industry. It is due to the release of chemicals such as hydrocarbons or polychlorinated biphenyls released by industries and discharged water from factories. It impacts air quality and enters the soil through discharged water from industries causing environmental problems such as air pollution and land degradation.

- Agricultural pollution

Agricultural pollution is defined as the waste or discharge from farm activities. It is caused by animal manure and plant protection products/pesticides (herbicides, insecticides, fungicides) contained in fertilizers and used in agriculture, which then enter the soil until they reach the groundwater.

- Domestic pollution

Domestic pollution is caused on the land by the daily use of household things, such as wastewater from the kitchen, the bathroom, and the laundry room. Wastewater from toilets, cleaning products or cosmetics (laundry soap, detergents), paints, solvents, draining oils, and hydrocarbons are responsible for domestic pollution.

- Accidental pollution

Unexpected events beyond human control cause accidental pollution. It is caused by the accidental release of toxic products into the natural environment that disturbs the ecosystem. For example, it may occur due to a pipeline rupture, fire, or sinking.

1.5.2 Physical degradation

Physical degradation is defined as the loss of the physical properties of the soil (Lal & Stewart, 2012). It refers to soil erosion, change in the soil's physical structure, and loss of soil organic carbon (von Braun et al., 2013). This type of degradation is widespread in cultivated soils in Africa. Physical degradation is the primary cause of diffuse water erosion and refers to erosion, soil organic carbon loss, and changes in the soil's physical structure (von Braun et al., 2013). Soil in the good physical condition is brittle, porous, and aerated, conditions necessary for a good rooting of plants, and its soil density in this state is about 1300 kg/m^3. According to Brabant (1992), anything that causes damage to the friability, porosity, or soil aeration is considered a physical degradation. For him, if the density of the soil is equal to or more than 1800 kg/ m^3, the soil is facing physical degradation.

As modalities of physical degradation, there are:

1.5.2.1 Compaction

Settling of the surface layer of the soil occurs. In general, compaction results from the repeated shift from heavy agricultural machinery to unfavorable periods of the seasonal cycle. Compaction due to the trampling of animals in overgrazed areas is more widespread. It allows the rapprochement between the soil particles, which favors the partial or complete loss of its absorption capacity (R. J. A. Jones & Montanarella, 2003). Compaction is frequently met in the area where the soil is wet. As consequences of compaction, Montanarella (2007) mentioned: the loss of soil fertility due to changes in the structure of the soil; the reduction of water infiltration and retention due to an increase in water run-off; the increase in greenhouse gases from the soil due to changes in the nutrient cycle; the depreciation in land value; the loss of soil biodiversity and increased susceptibility to erosion.

1.5.2.2 Mass taking

It is characteristic of savanna soils, in the top layer sandy to sandy-clay over a thickness of 20-40 cm. This layer, very loose in the rainy season, hardens like cement in the dry season. It is a constraint during the harvest period above all the tuber harvest, like yams or pod-like peanuts.

1.5.2.3 Crusting

Crusting is due to the impact of raindrops on the ground poorly protected by vegetation. The clods crumble, and a thin layer of clay, silt, and sand stratified a few millimeters thick covers the surface as a sort of frosting of the soil.

1.5.2.4 Changes in soil water regime

Changes in soil water regimes directly result from reduced or increased soil infiltration capacity. Indeed, since the permeability capacity of the soil is reduced, it is submerged during the rainy season, and the excess water favors water erosion which can take different forms. On the contrary, soil water reserves are lower during dry periods due to the lack of infiltration. The soil becomes too wet or too dry depending on the season, creating disorganization of the soil structure.

1.5.2.5 Soil erosion

Erosion is the detachment and transport of soil particles caused by natural or anthropogenic erosive forces such as water runoff, rain, wind, tillage, land leveling, and crop harvesting.

It is subdivided into two main processes: water erosion and wind erosion (Baartman et al., 2007). Water erosion is the process by which rainwater detaches and transports the particles of soils, and it is related mainly to runoff. Water erosion is frequently met in Côte d'Ivoire in the rainy season. In the case of wind erosion, soil disintegrates under the influence of the wind, and this process mainly affects the northern part of the country.

1.6 Causes of land degradation

Numerous causes of land degradation are grouped into two categories: natural and human-induced causes (Barman, Mandal, Bhattacharjee, & Ray, 2013; IPBES, 2018b; Sivakumar & Ndiang'ui, 2007; World Meteorological Organization, 2006). Some authors regrouped the causes of land degradation into proximate and underlying causes. Proximate causes directly affect the terrestrial ecosystem and can be natural or anthropogenic (unsustainable land management). Underlying causes are the causes that indirectly affect proximate causes of land degradation. These are institutional, socioeconomic, and policy factors ecosystem (O. K. Kirui & Mirzabaev, 2015; Mirzabaev et al., 2016a).

As mentioned above, land degradation is caused by natural and anthropogenic direct causes that are sometimes shaped by indirect causes. Natural causes such as landslides, droughts, earthquakes, tsunamis, avalanches, mudflows, floods, and volcanic eruptions are responsible for land degradation. For human-induced causes, they can directly or indirectly lead to land degradation. We can quote bushfires, deforestation, overgrazing, industrial pollution, urbanization, mining activities and quarrying, poverty, and change in weather and climate. Table 3 summarizes the potential causes of land degradation in Ivory Coast.

1.6.1 Natural causes of land degradation

Natural causes are causes beyond the reach of humans or cause that humans don't have control over. These are landslides, droughts, earthquakes, soil erosion, tsunamis, avalanche, mudflows, floods, and volcanic eruptions. The natural causes occur episodically, with periodicities ranging from years to millennia. They are sometimes responsible for land degradation, loss of biodiversity, and ecosystem functions and services (IPBES, 2018b; Z. Li et al., 2015). However, in Ivory Coast, the influence of natural causes in land degradation is limited because the country didn't experience natural causes such as earthquakes, tsunamis, avalanche volcanic eruptions, and mudflows. The natural causes experienced by the country are landslides, drought, and floods.

1.6.1.1 Drought

Drought is a natural phenomenon characterized by a prolonged lack of water that affects soils and vegetation. It is an abnormally dry period long enough to cause severe hydrological imbalance (IPCC, 2012). A drought event can be one-time or cyclical. It is caused by water deficit, high temperatures, and sometimes excessive water consumption for human activities. Indeed, in the event of insufficient precipitation, water reserves cannot recharge as they should maintain a hydrological balance. If high temperatures accompany this lack of water, this results in a natural increase in evaporation and evapotranspiration of plants resulting in drying and soil erosion leading to drought. Also, when water supplies decrease due to unfavorable weather conditions, humans do not always manage them effectively in their agricultural, industrial, and domestic operations. Over-exploitation of water resources can lead to the drying up of water tables and threaten their sustainability. The lack of water causes a disorganization of the soil structure, leading to soil degradation. As types of drought, we can quote meteorological drought caused mainly by precipitation deficit, agricultural drought caused by soil moisture deficit, and hydrological drought caused by a depletion in water storage or streamflow (Mukherjee et al., 2018).

1.6.1.2 Landslide

Landslide[6] is the rapid downward movement of a mass of rock, earth, or artificial fill on a slope. According to Cruden (1991), it is the movement of a mass of rock, earth, or debris down a slope. It can happen by fall, topple, slide, spread, or flow of mass of rock, debris, and soil. It sometimes occurs when the natural slope part can no longer support its weight. Usually, landslides happen in areas with steep slopes, and they can happen in areas with low slopes or relief. It is caused by:

- The weakness in the composition of some structures of soil or rock formations,
- Intense and heavy rain
- Changes in groundwater level
- Earthquakes or volcanic activities
- Erosion due to continuous runoff over a slope.

Landslides can be distinguished into four main types (Zorn & Komac, 2013) that are:

- Earthfall

It occurs on steep slopes by the detachment of the ground along a surface on which slight shear displacement occurs.

- Earth slide

It occurs on moderate and steep slopes. The weathered shallow soils slide on a more resistant or impermeable substrate.

- Earth topple

It happens on vertical slopes with cohesive materials. The formation of joints or cracks behind the slope's edge causes a forward rotation of part of the ground.

- Earth flow or mudflow

[6] https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/infosheet_landslide_classification.pdf

Earth flow occurs on moderate slopes during or after heavy rains and involves a reduction or transformation of solid materials into slippery materials. In Ivory Coast, landslides sometimes happen after a long and heavy rain in the mountain part and some area with steep slopes.

The consequences of landslides are many. These are loss of soil fertility, destruction of infrastructure and property, reduction of economic activities due to road interruption, and soil contamination due to the destruction of some infrastructure (Montanarella, 2007).

1.6.1.3 Flood

Flooding is a rapid or slow submersion of an area that is usually out of water. It is also the accumulation of water over sites that are generally not submerged (IPCC, 2012). Flood results from crossing two components: the water outlet from its usual drainage bed and the man who settles or is installed in a flood zone of the constructions.

The saturation of soil generally causes flooding by water or soil impermeability. It can also happen if soil infiltration capacity is less than rainfall intensity. The fact that the saturation of soil generally causes flooding by water or the impermeability of soil by water and when the capacity of soil infiltration is less than rainfall intensity is sometimes responsible for landslides or erosion (R. J. A. Jones & Montanarella, 2003). There are four main types of flooding. These are the direct overflow of a stream that flows out of its minor bed into its central bed; daily or catastrophic submersion of marine waters; indirect overflow by rising alluvial aquifers; stagnation or stormwater runoff due to inadequate capacity for infiltration and drainage of soils during unprecedented rains.

1.6.1.4 Soil erosion

Erosion resulting from the threshing of water drops and the transport of solid particle matter from runoff is also one of the causes of soil degradation in the country (MINEDD, 2014). It is primarily influenced by soil texture, structure, organic matter content, and permeability. In general, soils with greater resistance to erosion are those in which water infiltrates more rapidly, are rich in organic matter, and with improved structure. The more the slope of the field is steep, the erosion risks are significant. Erosion increases if the soil is not sufficiently protected by vegetation cover and a steeper slope. It is the case in the western part of the country, where we have some mountains where farmers like to grow crops. The vegetation cover protects the soil from the impact of the raindrop, tends to reduce the speed of runoff, and promotes water infiltration into the ground. Also, vegetation cover protects the soil against wind erosion in arid climates where rainfall is less than 600 mm on soil and winds exceed a threshold of 20 km/h or 6m/s on dry soils.

1.6.2 Anthropogenic causes of land degradation

Anthropogenic causes are the causes that derive from human activities, and they influence land in its process of degradation. Two types of anthropogenic causes are distinguished, and these are direct and indirect anthropogenic causes.

1.6.2.1 Direct anthropogenic causes

Direct anthropogenic causes of land degradation can be conceptualized as human activities that lead directly to land degradation. They are mainly agriculture-related (Geist & Lambin, 2002a; Zorn & Komac, 2013), above all in developing countries, particularly in Ivory Coast, where the economy is based on agriculture (REEA, 2016). As direct anthropogenic causes, we can quote deforestation, change in weather and climate, overgrazing, intensive agriculture, urbanization, bushfires, mining, and quarrying activities.

- Bushfires

The practice of bushfires contributes significantly to the degradation of land and vegetation cover in Ivory Coast (MINEDD, 2014). Bush fires are a real scourge in Ivory Coast. They cause damages in economic and social terms, the most direct of which is the destruction of plantations, infrastructure and sometimes even the loss of human life. From an environmental point of view, wildlife is destroyed. Worse, bushfires are accelerators of land degradation. It should be noted that bushfires are made by men who use fire daily for various purposes. Their size and extent were quite limited in Ivory Coast until the 1970s. During the drought of 1973 and 1983, bushfires reached alarming proportions. Bushfires seriously destroy forests and natural resources such as soil. They damage many trees and progressively destroy the soil by disappearing humus and organic matter and exposing these soils to sun, wind, and rain. The causes of bushfires are many. They are used to regenerate pastures for breeders, control epizootic parasites, and burn piles formed after clearing to clear the land by farmers. Hunters also use bushfires to flush animals etc.

- Change in weather and climate conditions

Change in weather and climate condition contributes to land degradation (Nachtergaele et al., 2010). It refers to the variation of temperature and precipitation within regions or countries. It increases land degradation by accelerating evapotranspiration, the frequency and intensity of climate-related natural phenomena such as drought and flooding (GNACADJA, 2013). According to IPCC (2019), human activities are responsible for the change in climate and weather conditions. Indeed, in goods production, to solve the population need, some greenhouse gas (carbon dioxide, methane) are released into the atmosphere and added to those already present in the atmosphere to contribute to the change in weather and climate condition. Change in weather and climate conditions influence land and lead to degradation. Precipitation is an important factor that leads to land degradation. High temperature and low precipitation lead to low organic matter production in soil and rapid oxidation, leading to low aggregation and vulnerability to erosion by wind and water. Less and over precipitation affect land by desertification or excess, leading to soil erosion.

- Deforestation

Deforestation is when some trees are cut down or burned for human use (Barman, Mandal, Bhattacharjee, & Ray, 2013). Since 1935 deforestation has been identified as one of the leading causes of land degradation (Stebbing, 1935). Ivory Coast forest, which accounted for 15 percent of the territory in 1986, declined to less than 9 percent in 2019 (UK Space Agency, 2020).

According to REDD[7]+ Ivory Coast online platform one article, the country is the first African country with the highest deforestation rate. This deforestation is due to the growth of the population, which leads to expanded needs for crops, grazing land, and energy. Also, because the country based its economic development on agriculture, the increase in the area cleared for cash crops such as coffee, cocoa, and oil palm has been detrimental to the forest. The Centre east regions, which constitute the last reservoir of the rural forest of the country, are faced with 50% of deforestation. Concerning the Western part of the country, forest loss represented over 7% of its cover. The inconvenience of deforestation is that it reduces evapotranspiration, interception of runoff, infiltration rate, and tree root strength and increases raindrop impact (Bojo & Cassells, 1995).

[7] http://reddplus.ci/la-cote-divoire-1er-africain-en-terme-de-taux-de-deforestation/ (assessed Feb 28, 2021)

- Intensive agriculture

With the increase in the Ivorian population from 6,709,600 in 1975 to 29,389,150 million inhabitants in 2021 (INS, 2021), the need for food has become increasingly apparent. Many farmers are using chemical fertilizers and manure applications to increase production to address this problem. However, these practices lead to excess nitrogen and a concentration of nitrates in the water, leading to soil pollution. Also, using plant protection products to increase agricultural production harms the environment as they remain in the environment for a long time and contribute to land degradation.

- Mining and quarrying activities

The geology of Ivory Coast favors several types of mineralization. Several indices of mineral resources are distributed over the Ivorian territory (Koffi et al., 2014). The statistics published by SODEMI[8] in 2007 attested the existence of at least five gold deposits, two diamonds, eight iron containing more than 33 percent of the ore, three which combine iron and titanium, seven of nickel, two of manganese, three of mineralized sands, two of Tantalite, seven bauxite containing 35 to 55 percent aluminium oxide, more than twenty granite, marble, and ornamental stone deposits, two industrial glass sands and four clays (KATENDI, 2009 as cited in Koffi et al., 2014). This attracts many people to engage in this activity, whether clandestine or official, to adjust their income (Denis, 2016). In the mining process, since the ore is trapped under a layer of soil or ordinary rock, it must be moved or excavated to allow access to the ore repository. It is at this stage where the degradation of the environment, and more particularly that of the land, occurs. Indeed, this degradation is manifested by spills, leaks of hazardous materials, and wind-whipped contaminated dust deposits, leading to soil contamination. As types of mining and quarrying activities, we can quote: open pit mining in which the ore deposit extends deep into the subsoil requiring the removal of layers of land and ore, placer mining which is used when the metal of interest is associated with sediments in a stream bed or floodplain, and underground mining in which a minimum amount of land is removed to access the ore deposit. For underground mining, access to the ore deposit is through tunnels or wells.

[8] Entity in charge of mining development in Ivory Coast

- Overgrazing

Overgrazing is when livestock exerts excessive vegetation consumption (Catto, 2013). It is more pronounced in the northern part of Ivory Coast because of the increasing flow of animals from the Sahelian countries to the country. It is associated with extensive rearing; it causes a reduction or disappearance of the vegetation cover and an increase in the compactness of the top layer of the soil (Kiage, 2013; Papanastasis, 2009) the formation of gullies, and erosion of gullies. There is physical degradation, followed by water erosion and sometimes wind with overgrazing.

- Urbanization

Ivory Coast is experiencing extremely rapid urbanization. Urbanization reduces biomass production, destroys productive land, and leads to land degradation through infrastructure development (Geist & Lambin, 2002 as cited in Barman et al., 2013). It is the consequence of urban population growth. The least urbanized country in West Africa in 1960 is now ranked among the most urbanized countries in the sub-region. From 12 percent in 1960, the rate of urbanization increased to 51 percent in 2014 (DIBY, 2018; INS, 2014). This rapid urbanization linked to industrialization has allowed the disappearance of nearly 50 percent of the vegetation cover, especially in urban areas such as Abidjan (DIBY, 2018), because of the requirement of some infrastructure like transportation, housing, water, commerce, recreation school, etc.

1.6.2.2 Indirect anthropogenic causes

Indirect anthropogenic causes of land degradation do not directly lead to land degradation but play a role in its degradation process through some direct anthropogenic causes (Díaz et al. 2015, as cited in IPBES, 2018). Population growth, insecure land tenure, pollution from industries, and poverty are some examples of direct anthropogenic causes.

- Population growth

Population growth exerts pressure on natural resources, especially those in rural areas, and creates a need for more resource management systems (Todaro 1982, as cited in Wachter, 1992). It can lead to reducing fallow periods. With an annual population growth rate of 2.6 in Ivory Coast, the consumption of resources such as land, food, water, fossil fuels, and minerals has become essential. Waste products due to the consumption of resources such as air and water pollutants, toxic materials, and greenhouse gases lead to land degradation. They increase greenhouse gases, mainly from carbon dioxide emissions.

- Insecure land tenure

Insecurity land tenure is viewed as disputed property rights, the absence of property, or open access (Wachter, 1992a). It plays an essential role in the process of land degradation in Ivory Coast. There is no incentive to use land sustainably because, in some regions of the country, land is often rented, sold to several people simultaneously, or subject to conflict. In the western and southwestern parts, conflicts frequently happen in which people die (N. F. Kouassi & N'drin, 2016). Thereby, the land users don't take care of it for fear that their investment will not benefit them. If the land right is clearly defined, entirely and exclusively assigned, land users would be incentivized to invest in their land. Also, the willingness to invest in land conservation will increase to take care of their land resources and use them in a socially optimal way (Heltberg, 2002; Wachter, 1992a). However, land tenure security is difficult to achieve because it transforms customary rights into individual holdings (Berry et al., 2003). This transformation has the potential to generate or worsen social and economic divisions. Insecure land tenure is related to poverty that contributes to land degradation.

- Pollution from industries

Industrial pollution in some companies' production processes causes land degradation (Barman, Mandal, Bhattacharjee, & Ray, 2013). Indeed, industrial effluents such as stack gases of all kinds, heavy metals, and wastewater containing many pollutants are introduced onto the land by air or water, leading to land degradation. Also, some wastes are directly released on open land in huge quantities (Kedi et al., 2020), seriously damaging the land and polluting the environment. Although the country is not industrialized, the few industries with high carbon dioxide emissions (Dongo et al., 2013), especially cement and plant protection products, which have undergone a significant change in recent years, are responsible for the pollution of waterways and even the air. For plant protection products, apart from the direct degradation by the waste released on the land and the pollution of the atmosphere, they produce inputs that farmers use for weeding that degrade the land.

- Poverty

Poverty is an underlying factor of land degradation (von Braun et al., 2013). It is a factor that contributes to land degradation through its influence on the decision-making and the time horizon of users of land resources. Its effects can severely constrain the mitigation of land degradation. Poverty becomes a contributory cause of land degradation because it reduces farmer adoption of sustainable land management practices (Berry et al., 2003). It also becomes a consequence of land degradation through the reduction of income when land productivity declines. Land degradation occurs when farmers, herders, and others who depend directly on land resources cannot wait for the land and vegetation to recover for reuse (ELD Initiative & UNEP, 2015). The poorest people struggle daily for survival; this means they have no long-term planning for land degradation. In the country, poverty plays an important role in land degradation in rural areas, where the rate was 57 percent. The poverty headcount rate was 46.3 percent in 2015 (PNUD, 2017). For the urban poverty rate, it was 36 percent. It acts as a constraining factor for farmers to invest in sustainable land management. The poor farmer who cannot hire labor use sometime bushfires or pesticide to clear their land, thus contributing to the degradation of their land.

Table 3: Natural and anthropogenic causes of land degradation

Natural causes	Direct anthropogenic causes	Indirect anthropogenic causes
Drought	Bushfires	Population growth
Landslides	Deforestation	Insecure land tenure
Flood	Intensive agriculture	Pollution from industries
Erosion	Mining and quarrying activities	Poverty
Landslide	Overgrazing	
	Changes in weather and climate conditions	

Source: author compilation

This practice not only degrades land by destroying its upper layer where humus is located but releases greenhouse gases into the environment.

1.7 Consequences of land degradation

Land degradation in Ivory Coast is a serious threat to biodiversity, stability, and the function of ecosystems. A range of plant and animal species are threatened by habitat loss. The depletion of biomass due to clearing and further erosion of the earth's surface produces greenhouse gases contributing to climate change and global warming. Because of the interconnectivity between ecosystems at various scales, land degradation triggers destructive processes that can have multiple impacts on the biosphere. The consequences of land degradation can be classified in the case of

Ivory Coast into two groups. These are social and economic consequences and environmental consequences. The social and economic consequences of land degradation can be summarized as follows: loss of soil productivity, reduction of agricultural productivity, increased commodity costs, the prevalence of invasive species, exposure to food insecurity, increase in the poverty rate, and migration.

In terms of environmental consequences, land degradation promotes dryness, reduction of biodiversity, erosion, and air pollution through the death of plants and trees that absorb atmospheric gases responsible for climate change.

1.8 Climate change and land degradation

With poor land management, climate change is one of the main vectors of land degradation. According to IPCC (2019), Climate change exacerbates land degradation and accelerates it through heat stress, drought, changes to evapotranspiration rates, and biodiversity. High temperatures and low rainfall make the country particularly sensitive to the prejudicial interactions between land degradation and climate change. Changes in temperature and humidity, combined with reductions in soil organic matter, biomass, and soil fertility, can cause land degradation. Also, increasingly frequent extreme weather events, such as severe droughts or heavy rainfall, are likely to exacerbate wind and water erosion, contribute to further biomass reductions and land's physical and chemical degradation (UNCCD, 2015).

The feedbacks between climate change and land degradation are extremely complex. Due to the loss of carbon reserves in soils and vegetation, these processes can be self-restrained when land degradation contributes to climate change. Besides, land degradation, caused by reductions in vegetation cover and unsustainable land management, influences the local microclimate. This influence is manifested by decreasing air humidity and increasing soil temperature. It is narrowly linked to climate variables, such as temperature, precipitation, wind, and seasonality (Olsson et al., 2019). Over time, the reduction in vegetation cover increases the amount of solar radiation reflected by the earth's surface, which has a cooling effect on the earth's global temperature (UNCCD, 2015). Land degradation and climate change can disrupt existing ecological and land-use systems, leading to food and water supply failure. Therefore, it is essential to have his direct links with climate change.

1.8.1 Direct linkages of land degradation with climate change

The direct effects of climate change responsible for land degradation encompass increased temperatures, rainfall patterns changes, and rainfall intensification (Olsson et al., 2019). These changes increase the soil erosion rate, which is one cause of land degradation. Global warming induced by humans has caused an increase in the frequency, intensity, and amount of heavy precipitation, which amplifies soil erosion. The second one, precipitation intensity, is a key climatic driver of soil erosion (Olsson et al., 2019). Changing precipitation patterns can lead to vegetation modification which may impact land and cause degradation (Shao, 2008). They affect biological processes useful for land fertility (Olsson et al., 2019).

An increase in temperature has a direct effect on land degradation. These effects are two kinds and focus on nitrogen and carbon cycles in the soils and permafrost melting in some areas, such as in the northern hemisphere.

1.8.2 Indirect linkages of land degradation with climate change

Agriculture is one of the more important indirect linkages between land degradation and climate change. The reduction of agricultural productivity results from climate change in combination with other drivers (Porter et al., 1991). Changes in precipitation and temperature affect land and crop management in the planting and harvest period (Z. Li & Fang, 2016). These changes in climate may increase cropland into natural ecosystems, intensification on already cultivated lands or arable lands

1.9 Climate change as a threat multiplier in Ivory Coast

Climate change is a threat in Côte d'Ivoire, especially in environmental, economic and social plans.

1.9.1 Climate change as a threat to the economy and social plan

Like most African countries, Ivory Coast contributes only marginally to the greenhouse effect but suffers from the horrors of climate change. By 2050, the country is expected to face rising temperatures, changing precipitation, and rising ocean waters (World Bank, 2018). Climate change could reduce its GDP by 2-4 percent by 2040 and 10-25 percent by 2100, as in the continent's other countries (IPCC, 2019a), corresponding to an equivalent loss to FCFA 380 to 770 billion. These losses would be recovered between the agricultural sector, which is the leading sector of the economy, human capital, and infrastructure. Climate change could push 2 to 6 percent of households into extreme poverty by 2030, estimated to be nearly 1 million more people in extreme poverty and add to the 6 million poor today (World Bank, 2018).

1.9.2 Climate change as a threat to the ecosystem

Climate change threats the ecosystem through changes in average weather conditions. Indeed, although climate change is not the only one responsible for the transformation of the ecosystem, it plays an essential role in the ecosystem properties (nutrient cycling, energy and material flux). The sensitivity and response of ecosystems to climate change are due to complex interactions between microorganisms, disturbances and other factors (Malhi et al., 2020). By driving biodiversity loss, climate change negatively impact the ecosystem via land use change.

1.10 Conclusion

Land degradation and climate change are important contributors to environment degradation. Their causal effects have been established and particular attention must be taken into account to reverse their negative effects on the environment. The causes of land degradation are grouped into natural and human-induced causes. These causes are not only contributed to land degradation but also increase climate change. Conversely, climate change is essentially due to human activities and it influences the environment and threats land which is a vital resource for humans, animals and vegetables. The consequences of these two phenomena are many. So it is very important to reverse them to improve the welfare of the population.

2.0 CHAPTER TWO: DRIVERS OF LAND DEGRADATION IN TRAYS ECOSYSTEM

2.1 Introduction

Land degradation is a global ecological problem (IPBES, 2018a). It directly impacts the livelihoods of millions of people, especially the poorest and the most vulnerable living in the world's drylands. It also hurts the ability to increase global food production (Reed et al., 2011), which is necessary to meet the food needs of a rapidly growing population projected to exceed 9.2 billion in 2050 (Fukase & Martin, 2017). Land degradation is increasing significantly worldwide, covering around 23 percent of the global land (Saguye, 2017). It is more pronounced in developing countries (Cerretelli et al., 2018b; Mirzabaev et al., 2016b), especially in Sub-Saharan Africa, where the economy is focused on agriculture (Nkonya et al., 2008). Indeed, agricultural productivity in this region has declined because of poor inherent soil fertility, biophysical factors, and climate changes.

Ivory Coast, one of the Sub-Saharan African countries, has its economic foundation in agriculture. Despite the country being endowed with enormous biophysical potential, it needs healthy soil to sustain its economy and people's livelihoods; above all, its economy is focused on agriculture (ibid). Agricultural productivity is declining despite the increase in the production of some crops due to extensive agriculture. This decrease in agricultural productivity is partially due to climate change, land degradation, and unsustainable land management (World Bank, 2019a) Closely interwoven with climate change, land degradation has given rise to a multitude of policy responses across the world (Batunacun et al., 2019). However, it still increases, and its impacts are several for developing countries, particularly those in Sub-Saharan Africa, like Ivory Coast. Since its independence, the country has suffered from land degradation. In recent decades, this situation has worsened with a degradation rate of 11 percent of its territory, around 3.547.093 ha of soil from 2000 to 2010. The lands presenting a net productivity decrease are around 1.607.454 ha, and the carbon stock has decreased by 444.384 tons (MINSEDD, 2017).

Understanding and identifying the drivers of land degradation are necessary for implementing policies and measures that will help reduce negative trends to have more socially and environmentally friendly outcomes (von Braun et al., 2013). The drivers of land degradation are complex and diverse, varying from one region to another and across the region (Batunacun et al., 2019; FAO, 2015; Mirzabaev et al., 2016b; Salvati & Zitti, 2009b). Their impact on natural resources includes functions and services of soil that affect biodiversity, environmental health, and human welfare (FAO, 2015).

In Ivory Coast, despite the lack of assessment of relevant drivers of land degradation, the causes are essentially anthropogenic. These are urbanization, overgrazing, mining and quarrying activities, intensive agriculture, deforestation, etc. Sometimes, the causes are natural such as drought, landslides, floods, and water erosion. Erosion resulting from the threshing of water drops and the transport of solid particles by runoff is the country's most serious form of soil degradation (MEDD, 2014).

This study about the drivers of land degradation in Ivory Coast aims to analyze the drivers of land degradation in the trays ecosystems. The specific objective is to identify the key drivers of land degradation in trays ecosystems in the country. The hypothesis on which this study is focused is that the decreasing precipitation and/or the increasing temperature lead to land degradation.

This study uses logit regression to achieve our objectives. It is structured as follows: section 2 overviews the drivers of land degradation. Section 3 presents the literature review. Concerning section 4, it deals with the materials and methodology, section 5 shows the results and discussion, and section 6 concludes the study.

2.2 Overview of drivers of land degradation

Drivers of land degradation encompass the external factors that can act directly or indirectly to result in biodiversity declines and quality of life (Barger et al., 2018). They can be classified into direct and indirect drivers (Barger et al., 2018; IPBES, 2018a). Kirui, (2016); Mirzabaev et al. (2016) distinguish two categories of land degradation that are proximate and underlying causes; similar are those mentioned above. Direct drivers can also be natural or anthropogenic, and they have an impact on the implementation of ecosystems (Barger et al., 2018). Natural drivers are those that are beyond human control, while anthropogenic drivers are the result of human decisions and actions. Concerning indirect drivers of land degradation, they are underlying causes and act on the direct drivers of land degradation. They act on how humans manage and interact with their ecosystem (Barger et al., 2018). These are subdivided into five categories that are:

- Demography: it includes population growth rate, migration and population mobility, the density of the population, and age structure.
- Economy, focusing on demand and consumption, commercialization and trade, labor market, prices, and finance.
- Science, knowledge, and technology: concerns education, indigenous and local knowledge, taboos, research and development investments, access to technology, innovation, and communication.
- Institution and governance: public policy, property rights, customary laws, certifications, international agreements and conventions, informal institutions, and competencies for formal institutions.
- Culture, for his part, concerns values, religion, worldviews, consumer behaviour, and diet.

Natural drivers of land degradation include earthquakes, volcanic eruptions, landslides, floods, droughts, hurricanes, typhoons, and periodic outbreaks of pests and pathogens. The frequency of their appearance varies from year to millennia and contributes to land degradation, biodiversity, ecosystem function, and services loss. The anthropogenic drivers of land degradation are essentially focused on the misuse of land. According to Batunacun et al. (2019), nine variables can account for anthropogenic drivers of land degradation. These are the distance to the nearest urban centre, the distance to the nearest rural settlement, the distance to the nearest mining area, the distance to the nearest road, the distance to the nearest surface water body, the human population density, the livestock density, the mean growing season temperature, and the annual sum of precipitation. For Dimobe et al. (2015), the drivers and the causes of land degradation are the same. For him, agricultural activity is the most important driver of land degradation, followed by deforestation, road network development, urbanization, and bushfire. All these drivers are considered anthropogenic drivers.

2.3 Literature review

This section reviews the evidence of land degradation, the possible drivers of land degradation in the country of study, the theoretical framework, and the empirical literature on drivers of land degradation. It focuses on direct and indirect drivers of land degradation.

2.3.1 Evidence of land degradation

Empirical evidence shows that the drivers of land degradation can be grouped into two categories: direct and indirect (Barger et al., 2018; IPBES, 2018a). Direct drivers are susceptible to direct effects on the terrestrial ecosystem and can be natural or anthropogenic. Indirect drivers act as the direct drivers of land degradation, and multiple factors explain them as the direct drivers of land degradation.

Geist & Lambin (2002) classified indirect drivers that lead to land degradation into five subgroups that are demographic, economic, technological, policy and institutional, and cultural. Among demographic factors, population growth due to high fertility plays an essential role in the process of degradation of land in developing countries (Berdimbetov et al., 2021). It is not a primary driver at the local scale, but its combination with other drivers accelerates the land degradation rate. The scarcity of land becomes recurrent, and the less it laid in fallow more it is susceptible to degradation.

Economic factors lead to land degradation in almost all developing countries. The economy mainly focuses on agriculture in these countries, and the countries benefit from cash crops. Commercialization, market failure, and the growth of some cash crops markets are some economic factors reported to drive deforestation and land degradation (Berdimbetov et al., 2021).

Concerning institutional and policy factors, some policies implemented, such as policy on land use and land tenure, sometimes incentivize the population to environmental degradation. In fact, in Ivory Coast, a few years ago, the government, aimed at encouraging farmers to produce more, subsidized the price of pesticides and fertilizers. This help has harmed the quality of some soils. Chemical elements allowed the disorganization of the physical and biological properties of the land. Also, corruption is sometimes considered as an institutional driver of land degradation because, in their attempt to get money from extractive activities through corruption, the administrative and political officials cannot encourage good policy implementation. According to Ceddia et al. (2015), improvement in governance indicators such as corruption generally can promote deforestation and accelerate land degradation by providing a more conducive environment for business investment. Land tenure arrangements and policy failures lead to land degradation. Property rights issues tend to have ambiguous effects on forest cover: unsecured ownership, quasi-open access conditions, misadjusted customary rights, and the legalization of land titles are all reported to influence deforestation and unsustainable land use in a similar manner.

For technological factors, the important process that affects land, deforestation, and environmental degradation are the changes in agrotechnological[9], agricultural intensification, and poor technical application of land use. Technology improvement is important in land degradation if it is not well applied. The heavy machine utilization in the field leads to soil compaction, one type of physical land degradation. Also, fertilizer and chemical use are supposed to increase the production and productivity of crops. Still, in the long run, they disorganize the soil structure, leading to degradation because the chemical products contained in them with a destruction power are infiltrated into the soil.

Cultural factors also play an essential role in the process of land degradation; they are primarily underlying economic and political forces. They influence the behavior of people looking for income, causing land and environmental degradation. Multiple socio-economic systems that support land use and predict land degradation are integrated into a specific cultural system of beliefs, values, and practices (Bélair et al., 2010 as cited in Barger et al., 2018). These land-use systems are dynamic, as shown by the emergence of various agroforestry systems through the long-term co-development of socio-ecological systems that incorporate cultural significance and management practices to reduce vulnerability to shocks or improve land-use sustainability systems (Hecht, 2014).

Associated with climate change, the indirect drivers play an important role in land degradation because they are essentially human-induced. Drivers of land degradation related to climate change focused on precipitation, temperature, wind, and evapotranspiration changes. Also, the changes in the intensity and distribution of extreme events are related to climate change (Olsson et al., 2019).

Multiple direct drivers explain land degradation (Geist & Lambin, 2002b). They are classified into subgroups: agricultural expansion, infrastructure expansion, and wood extraction, denoted by deforestation. The combination of these direct drivers dominates the broad clusters of direct drivers of land degradation. The first one, agricultural expansion, is a complex issue with many underpinning drivers. It is mainly responsible for land-use change and is associated with

[9] The technology of agriculture, as the methods or machinery needed for efficient production.

nearly all types of land degradation. It includes forest conversion for permanent cropping, shifting cultivation, cattle ranching, and colonization agriculture. The growing population needs more food and creates new consumption and production patterns for energy. Low productivity of smallholder agriculture in developing countries also leads to agricultural expansion because to increase their production, they seek new land where they practice agriculture.

Among all forms of infrastructure expansion, road construction is reputed to have an influence on land degradation above all those on slopes. The road is primarily considered a connection pathway for logging. During its construction, it drives soil erosion by compacting the soil surface and removing the protective vegetation cover essential for the soil (Yousefi et al., 2016). Road construction not only removed the protective vegetation cover but also fragmented the remaining vegetation cover. It consumes significant quantities of groundwater resources. The extension of overland transport infrastructure, deforestation, intensive and extensive agriculture, and cattle ranching are some direct drivers of land degradation (Geist & Lambin, 2002b).

The rapid expansion of population, unsustainable cropland management, and overgrazing are the main drivers of land degradation, causing biodiversity loss and impacting food security, water purification, energy provision, and other contribution of nature essential to humans. Indeed, to find out a location to live, people manage some areas for their housing and livelihood. This fact reduces agricultural land and leads to degradation because of the frequency and intensity of use of the remaining land; above all, these lands are not well managed. Land degradation is closely related to land management. When people don’t intervene in an area, the rate of degradation of this area is very low compared to when people occupy the area.

2.3.2 Identifying possible drivers of land degradation in Ivory Coast

In Ivory Coast, land degradation has many possible drivers and varies from one place to another place. Deforestation plays an important role in land degradation in the south-east and south-west regions reputed for their forest. Indeed, these regions are the main cocoa supply zone and have attracted hundreds of thousands of people from different parts of the country and neighboring countries, increasing population density (J.-L. Kouassi et al., 2021b). Deforestation in the regions mentioned above is mainly due to the establishment of agricultural plantations, particularly cash crops such as cocoa, coffee, rubber, and oil palm. Furthermore, the shift of cocoa basin in the 1980s from the east to the west caused by the expansion of cocoa plantations, illegal logging, and dense road network led to the removal of most forests and degraded the remaining land. Moreover, since the 1970s, a change in rainfall and temperature patterns has been observed in the country. This change in the climate is attributed to humans induced on the environment.

Several possible drivers include agricultural expansion and intensification, population growth, mining and carrying activities, illegal logging, overgrazing, poverty, urbanization, and insecure land tenure. In each part of the country, the possible drivers are not the same. For example, there are many potential drivers in the southern part of the country where the capital is located. We can quote that urbanization, pollution from industries, solid and liquid wastes, road construction, and population growth exert pressure on the land. Also, the southern part, which encompasses the coastal zone, is facing coastal erosion and a reduction in land availability. The rise of sea level due to the ice melting reduces and leads to land acidification which disorganizes the structure of the soil.

In the northern part, overgrazing is the possible driver of land degradation because this part is favourable for breeding. At this possible driver, compaction due to agriculture mechanization (N'Guessan et al., 2015) and repeated practice of bushfire before planting crops or hunting alter the structure of the soil. It also favors the encrustment of the soil surface, which makes the first rains very harmful to the soil. This phenomenon of crusting is widespread in the northern part of the country, where soils are derived from siliceous materials (MINSEDD[10], 2017).

The eastern part was initially the epicentre of cocoa production. From the 1970s, cocoa epicentre shifted successively to the Center-West, then to the South-West because of the reduction in the productivity of the land, the forest land availability, and the strong population migration. Migration and displacement of populations lead to increased pressure on forests and land.

According to Yao Sadaiou Sabas et al. (2020), the western part is the new cocoa epicentre where the remaining forest can be found. This area is reputed for agriculture and mining activity, and land is coveted by allogeneic, aboriginal, and strangers, according to Haby Niakaté[11]. The possible drivers in this part of the country are agriculture expansion, unsustainable land use, and pollution.

[10] Ministère de la Salubrité de l'Environnement et du Développement Durable

[11] https://www.lemonde.fr/afrique/article/2017/12/07/dans-l-ouest-de-la-cote-d-ivoire-une-terre-trop-convoitee_5226378_3212.html

2.3.3 Theoretical framework of land degradation

Environmental economics gives some pathways for analyzing human actions responsible for environmental degradation, such as land degradation and climate change. In environmental economics, theories explaining land degradation are related to the externality concept and population growth. For the externality concepts, the property rights approach, theories of social cost, and collective goods can be quoted to explain land degradation. Concerning the literature relating population growth to agriculture or natural resources, it has been dominated by Malthusian and Boserupian schools.

2.3.3.1 Malthusian theory

Malthusian theory is a theory focused on the growth of the population. It underlines that the growth of human populations always tends to exceed the productive capabilities of land resources, leading to severe environmental degradation, widespread famine, and violent conflicts. Malthus argued that population growth required an expansion of the agricultural land area to feed the population and that this expansion would occur increasingly over time on marginal lands of lower productivity (A.D & Kurian, 2016). The expansion of agricultural land can occur in two ways: (i) by clearing more of one's land or appropriating neighboring lands; and (ii) by migrating to other areas to develop new land for the agricultural purpose by forest clearing, which leads to deforestation and degradation of land. For this theory, the fact that population growth geometrically and the available food resources grow arithmetically exerts pressure on land. This fact allows overexploitation of land that leads to land degradation. The Malthusian theory has been criticized by several authors like Opperheim, Graham, Alexander Gray, and Nicolson. One of the Malthusian theory's arguments was that food production increases so slowly that it will eventually be unable to feed the growing population. Unfortunately, this is not the case in developed countries that use modern technology to increase food production. In addition, Malthus has forgotten that there are vast tracts of land that are lying barren and can be brought under plough, and that this land, when cultivated, can feed the growing population. Also, with globalization and trade, more food can be imported and supplied to feed the population, so focusing the analysis only on land and agriculture to provide food is wrong.

2.3.3.2 Contentious theory of Boserup

The contentious theory of Boserup starts with the relationship between population growth and food supply (Behrman et al., 2014). According to Boserup (1965), agricultural development is stimulated by population growth via innovation and productivity improvements. Indeed, as the population grows, land becomes scarce and must be used more intensively. For the author, the positive impact of population growth or density is agriculture innovations that would increase output to restore food production per capita and reduce a decline in living standards without necessarily increasing agricultural land area or reducing forest cover.

The gradual shift from extensive land use to intensive land use is almost characteristic of the sequence of agricultural development. As such, this transition is characterized by reducing fallow periods and increasing levels of agricultural intensity with fertilizer and pesticides. Reducing the fallow period and also using pesticides expose their land to degradation. Indeed, as the period of fallow is reduced, new technologies and methods must be adopted to improve the productivity of the land. Unfortunately, this fact is not taken into account by the great part of farmers that sometimes can't adopt new technologies and methods to improve the productivity of their land in developing countries. Like the Malthusian theory, the contentious theory of Boserup has been criticized. The major criticism was that the Boserup theory is not applicable in developing countries where the industrial sector is not developed. The hope of Boserup that the agricultural sector could absorb the growing population is not realistic for developing countries where the density is not low. Another criticism of the Boserup theory is that land intensification leads to land degradation (desertification, high rate of hydric and wind erosion) and population growth does not result in innovations or advancement taking the example of developing countries.

2.3.3.3 Property rights approach

The main concept of property rights began with Coase (Kim & Mahoney, 2002). Property rights are any formal or informal rights to use or transfer resources (Alston & Mueller, 2005). They range from open access to a fully specified set of private rights. They are important because they guide resource use. The more exclusive are property rights to the individual or group the greater the incentive to maintain the value of the asset.

In addition, exclusive rights provide incentives for improvement of the asset's value by investment. In environmental economics, the property rights approach considers that externalities cause environmental degradation. But for the property rights theorists, the problem is not the externalities that caused land degradation. The absence or poorly defined property rights to environmental goods such as land is responsible for land degradation. For them, if land rights were clearly defined, fully, and exclusively assigned, land users would be incentivized to invest in their land to take care of their land resources and use them socially (Heltberg, 2002; Wachter, 1992a). The fact that land rights are often imprecise, unspecified, contested, or non-existent is widely seen as a problem for developing countries. It pushes land users to not often invest in their assets to take care of them because they may escape to them at any time. According to Heltberg (2002), land rights and their enforcement give the security of tenure and hence the incentive to undertake investment in land. Exclusive property rights increase the incentive for investing in land conservation, to increase future income streams or to increase the value of land as a capital asset. The inconvenient of the property right approach is that in presence of transaction cost, the economic process may result in failure to reach the contractual agreement while in the zero transaction costs the economic process would be efficient (Kim & Mahoney, 2002).

2.3.3.4 Theory of social cost

Social cost are costs that are borne by members of society other than the firm and the consumers who cause them. They are unpaid cost by those who produce them (Neves, 2018). They include any external costs, or what are often referred to as simply externalities. According to Wachter (1992), the theory of social cost and the recognition of the relation and social goes back to Pigou (1920). Pigou argues that if economic agents do not fully bear the social costs of their actions, and if there are externalities, the production factors will not be optimally distributed, leading to the incapacity of the market to cope with the problem of externality itself (Wachter, 1992a). The theory of social cost may explain land degradation resulting from the use of practices for which farmers do not bear the total cost (for example, downstream costs of pollution or water erosion) or positive externalities (linked, for instance, to the protective functions or values of biodiversity) which cannot be monetized, forcing users to adopt unsuitable production practices. The inconveniences of the theory of social cost are many but the main inconvenience is that it is a critical problem to quantify social costs for damages or benefits in the future from current production. Also, social cost results from the non-existence of market either because of the absence of property rights or the transaction cost are prohibitive (Neves, 2012).

2.3.3.5 Theory of collective goods

Collective goods are goods that the consumption by one individual does not reduce the possibility for other individuals to consume them (Samuelson, 1954 as cited in Tinbergen, 1984). They are produced by publics authorities because their production are more cheaply than when private producers produce them. Many environmental goods have collective goods properties, particularly non-excludability and externalities. Collective goods have three properties: non-excludability, which means nobody can be excluded from consumption so anybody can benefit, nonrivalry in consumption which is the fact that one person's consumption does not impair that of another, and externalities which assume the possibility of free-riding because of non-excludability. However, when nonrivalry no longer applies to them, environmental problems arise. According to this theory, environmental problems occur when users exploit scarce environmental goods without contributing to their maintenance or conservation (Wachter, 1992b). One example used is grazing areas. Indeed, land users have no incentive to conserve land because conservation benefits are dissipated among all land users.

2.3.4 Empirical review on drivers of land degradation

Land degradation is a serious impediment to well-being in developing countries, particularly in sub-Saharan Africa (Mirzabaev et al., 2016b). According to Batunacun et al. (2019) and Mirzabaev et al. (2016), the drivers of land degradation are numerous and complex. Several studies pointed out that biophysical, institutional, and socioeconomic factors drive land degradation (O. Kirui & Mirzabaev, 2015).

For instance, Dimobe et al. (2015), in their study titled “identification of driving factors of land degradation and deforestation in the wildlife reserve of Bontioli,” investigate the drivers and the extent of land degradation. For them, LD is due to direct and indirect causes. After establishing the relationship between socioeconomic drivers and LULCC (Land use land cover changes) with binary logistic regression, they found a higher rate of land degradation in areas bordering the reserve while the core protected and inaccessible areas are comparatively low. The same study found that agricultural expansion is the most important direct cause in terms of severity. At this direct cause and taking into account the severity of the degradation, the authors add road network development, settlement expansion, and bushfire as the following causes. For indirect causes of land degradation and deforestation, the authors have found five socioeconomics and political factors that can influence the change in the vegetation cover. Poverty and population growth are the main factors that drive land degradation and deforestation in the study area. These drivers are followed by a shortage of off-farm employment, weak policy in favor of forests, and subsidies on farm input.

In assessing the relevant drivers of land degradation in three countries, Ethiopia, Malawi, and Tanzania, Kirui & Mirzabaev (2015) used a logit regression model with data between 1982 and 2006. For these authors, land degradation is classified into two categories that are proximate and underlying causes. The results of their study have shown that biophysical, demographic, plot level, and socioeconomic characteristics significantly influence land degradation. Biophysical variables such as rainfall, temperature, topography, and agroecological characteristics affect land degradation. The authors argued that land degradation in all countries of the study area is less to occur in the plains than in the highland.

Regarding the demographic variables, age and gender of the household head play a significant role in land degradation. Also, family size has not the same effect on land degradation in Ethiopia and Malawi. In Ethiopia, family size negatively affects land degradation, while it positively affects Malawi. In the same study, the authors found that plot level variables influence the likelihood of land degradation. The plot level variables include the slope of the plot, plot ownership status, soil type, and distance of the plot to the market. These variables significantly influence the likelihood of land degradation. Apart from these variables, secure land tenure, according to the authors, negatively influence land degradation. For them, the fact of having possession of a title deed reduces the probability of the degradation of land, and the reductions are respectively 3% in Malawi and Ethiopia and 4% in Tanzania. When they combined the model, the reduction proportion was 15%. Focusing on the regional characteristics, land degradation is significantly higher in Malawi and lower in Ethiopia, taking as the basis country Tanzania in the combined model.

Barman et al. (2013) have found two categories of causes concerning land degradation in their study in India. The two categories are natural causes and human-induced causes. The natural causes include earthquakes, tsunamis, drought, avalanches, landslides and mudflow, volcanic eruptions, flood tornados, wildfires, etc. For human-induced causes, we can quote climate change, deforestation, overgrazing, irrigation practice, urban sprawl and commercial development, pollution from industries, mining and quarrying activities, and agricultural intensification. According to the authors, the effects of these two categories of causes of land degradation are the reduction in agricultural productivity, migration, ecosystem and basic resources damage, food insecurity, loss of biodiversity, etc. The solutions and remedies given by the authors to alleviate land degradation are afforestation, the use of timber alternate, eco forests, and green businesses to manage deforestation. They also mentioned that irrigation, urban sprawl, mining and quarrying, and agriculture intensification must be addressed. They finished giving land reclamation as a solution and remedies, which consist of land productivity recovery.

Batunacun et al. (2019) have identified nine possible independent variables that account for drivers of land degradation in their study titled "Identifying drivers of land degradation in Xilingol, China, between 1975 and 2015". These variables created are urban: the distance to the nearest urban, road: the distance to the nearest road, mining: the distance to the nearest mining area, water bodies: the distance to the nearest surface water body; human population: the human population density; livestock: the livestock density; temperature: the mean growing season temperature, and precipitation: the annual sum of precipitation. Using partial ordered ranking of land degradation and the Hasse Diagram during the 1975–2000 period, the authors found that livestock density is the main dominant driver in six grassland counties in the study area. In the other five counties in the country, population and livestock density have had higher value effects. Taking only population density into account, the authors found that it has a higher value in one county. Still, in the same study, the authors identified the northern counties as part of the study area suffering from human disturbance. Indeed, human disturbance exerted a negative influence in eight counties. It was the dominant driver in eight counties with the strongest effects. Using the Hasse diagram for water conditions, the authors found three levels and three isolated elements corresponding to the counties. The three levels and the three elements mean that the diagram is weakly ordered, and there is no spatial pattern in the impact of water conditions on land degradation. Concerning urbanization, the Hasse diagram shows four levels and no isolated element, which means the diagram is strongly ordered.

Considering the 2000–2015 period, human disturbances factors remain the same as in the previous period. Livestock density negatively impacts six counties, and these six counties suffer from the high pressure of livestock density. About water conditions, three levels and four isolated elements are found, meaning that the driver of water conditions is weakly ordered while urbanization drivers have increased the number of ordered elements from one to five showing the impact of urbanization in the study area after 2000. Considering both periods, the authors found that urbanization has become more dominant than human disturbance and water conditions. Concerning the effects of water conditions, it decreased after 2000.

In his “the assessment report on land degradation and restoration,” IPBES (2018) identified eight direct anthropogenic drivers and five indirect drivers of land degradation and restoration. The direct anthropogenic drivers are grazing land management, cropland and agroforestry management, forests and tree plantation management, non-timber resource extraction, fire regime changes, the introduction of invasive species, extractive industry development, infrastructure, industrial development and urbanization. About the indirect drivers of land degradation, the report found demographic, economic, scientific knowledge and technology, institutions and governance, and culture. All of them play a crucial role in the process of land degradation. According to the report, extensive grazing land management, which is one category of grazing land management, accounted for 91 percent of the whole grazing land. Intensive grazing lands cover around 9 percent of the whole grazing land and are managed for livestock production. For the report, this fact translates to the impact of grazing land management on land degradation.

Mirzabaev et al. (2016) used the ordered probit model to identify the drivers of land degradation in their study titled “global drivers of land degradation and improvement.” The choice of the ordered probit model is justified by the fact that the dependent variable has three ordered categories. In the study, the authors found that higher population density and intense night-time lighting intensity, the proxy for higher socioeconomic development, are positively associated with land degradation. The relationship between night-time lighting and land degradation is convex. They found that areas with severe concerns over land tenure are associated with land degradation. The authors continued to say that the longer length of the growing period leads to more land degradation. In the same study, the authors found that less secure land tenure does not seem to be associated with higher land degradation in Sub-Saharan Africa. When they combined all results, the authors found that higher population densities and longer distances to markets lead to more land degradation.

Jiang et al. (2019), using boosted regression trees, have chosen eight potential drivers factors, namely precipitation, temperature, drought, canal, water withdrawal, salt discharge, population, and livestock, to explore their effect on land degradation in the Amudarya River delta. The results showed that near the Aral Sea in the downstream areas, some lands were severely degraded and water withdrawal availability and decreased precipitation were the factors that explained land degradation of cropland and sparse vegetation and grasslands from 1990 to 2000, respectively. For the period 2000-2015, the authors found salt discharge as the major force causing land degradation in different vegetation types. Their increase from upstream regions in sparse vegetation and grassland contributed to severe soil salinization, contributing to land degradation in the natural vegetation. Still, in the same study, the boosted regression trees model indicated that land degradation was most pronounced in areas where salt discharge to the field plot increased and water withdrawal was reduced. The authors also used the change vector analysis method to monitor ecosystems and research land-use change dynamics in the study area. This method focuses on the magnitude and direction of change in space among remote sensing images.

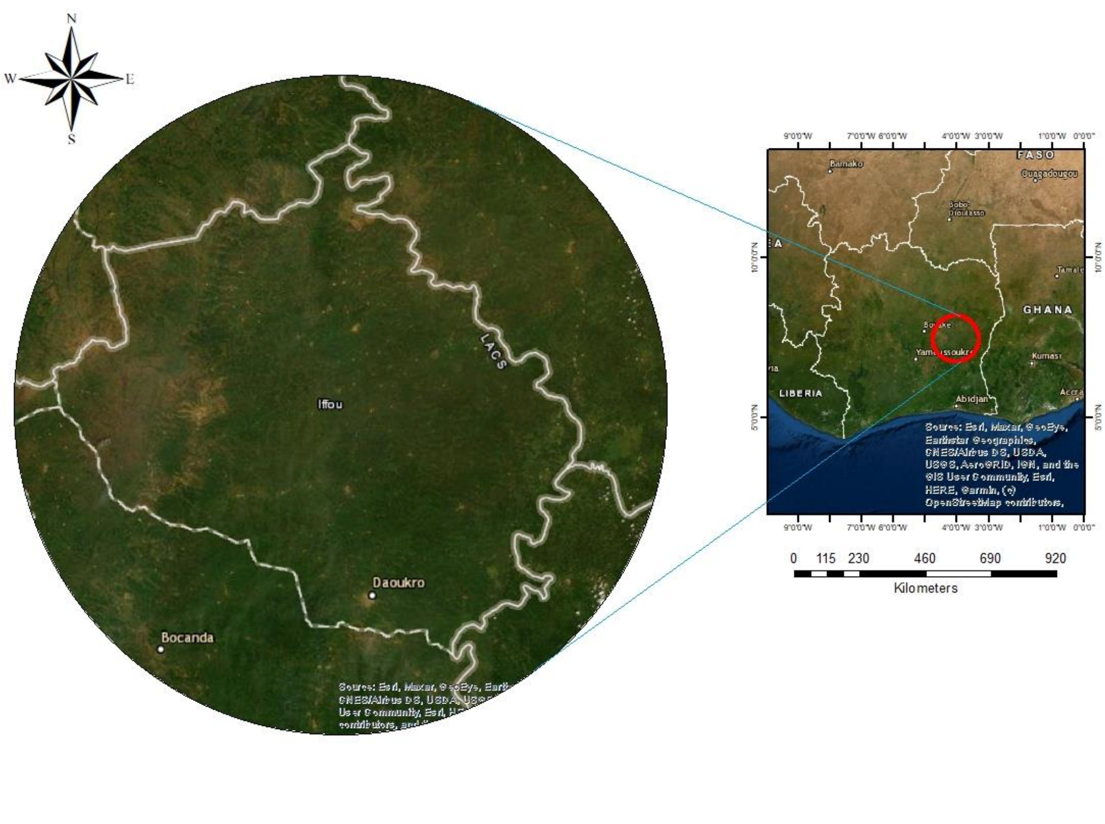
Perović et al. (2021), to identify the sensitivity of land degradation and deforestation in western Serbia, used the MEDALUS method. The authors have used also the principal component analysis (PCA) and multiple linear regression analysis (MLRA) to analyze the possible major drivers of land degradation. Three components have been identified as accounting for 77.9% of land degradation and deforestation. The first component is about vegetation quality index and management quality index accounting for 34.4% of the variance which indicates an anthropogenic influence on land degradation and deforestation. The second component accounting for 23.5% of the variance is soil quality index and social quality index. They indicate a natural/anthropogenic influence on Land degradation and deforestation. The third component is the climate quality index which accounts for 20% of the variance and indicates that the impact of land degradation and desertification can be attributed to climate variables. The results of their study revealed that degradation in the study area is more influenced by anthropogenic drivers. Also, the results showed that the critical area susceptible to be degraded accounts for 37% of the study area. According to the authors, the dominant anthropogenic factors identified as the main drivers of land degradation and deforestation are based on vegetation quality index and management quality index.

2.4 Material and method

2.4.1 Study area

The study was conducted in Ivory Coast, a West African country located between 4°30' and 10°30 of latitude North and 2°30' and 8°30' of longitude West with an area of 322,462 km^2 (A. M. Kouassi et al., 2022). The trays ecosystem is located in the country's central-eastern and northern parts. For our study area in this ecosystem, we have considered the “Iffou region,” located in the central-eastern part (figure 6). The choice of this region is because it is facing land degradation for two decades. It was the cocoa basin after the independence and now experienced depopulation because of the reduction of their agricultural productivity. The new cocoa basin is located in the South-western part of the country.

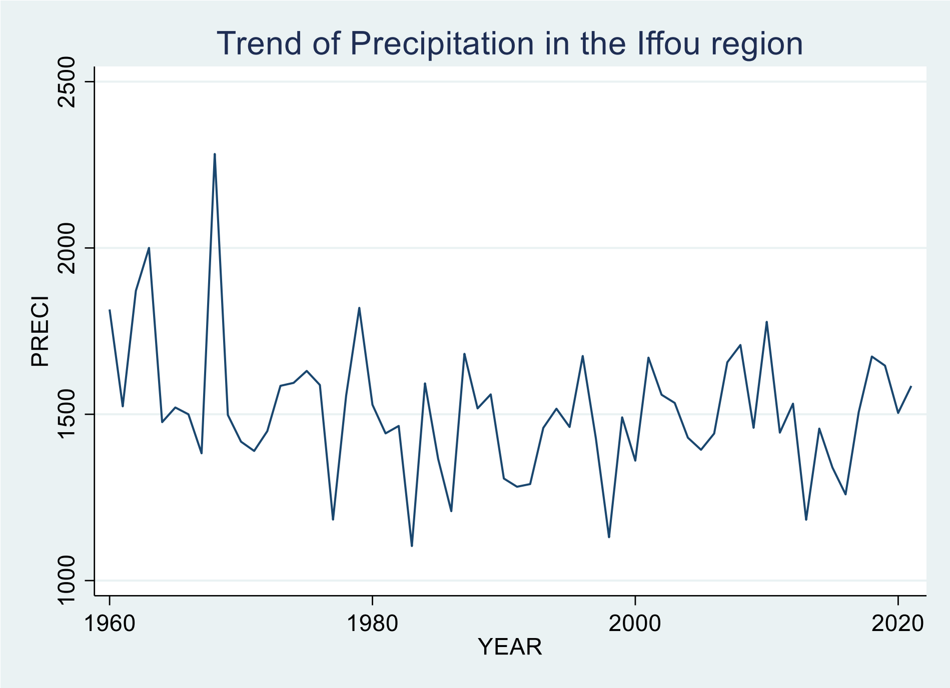
Figure 6: Study area



Realization: 2022 Source: author compilation

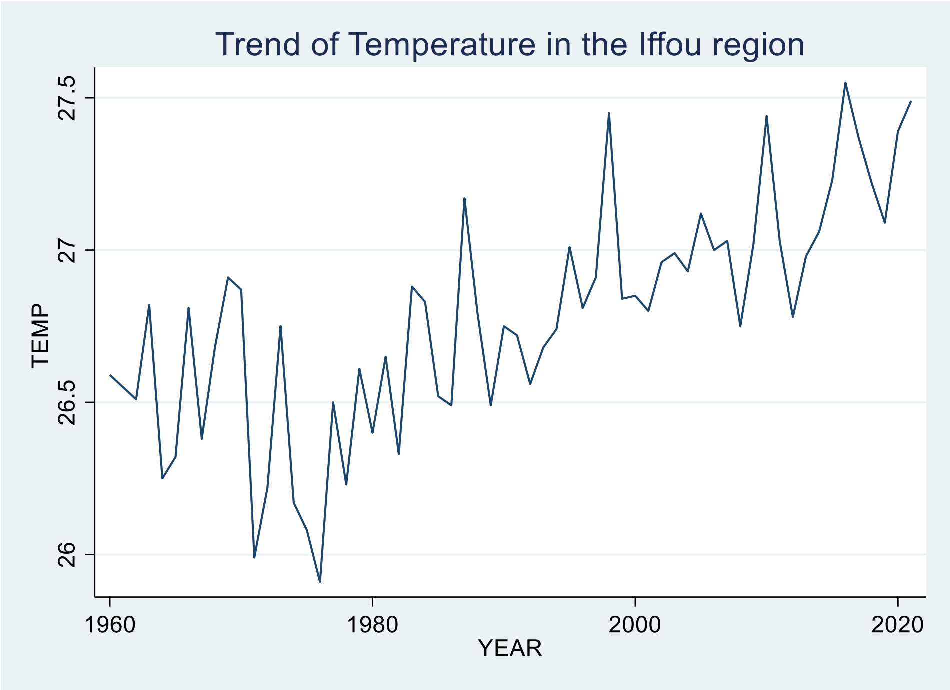
The Iffou region covers an area of 8955.05 km^2, and its population is estimated at 378,560 inhabitants (INS, 2021). The climate in this region is of the equatorial transition regime type (A. M. Kouassi et al., 2022). It is hot and humid (see figure 7&8) and alternates four seasons divided into two rainy and two dry seasons (KOUAKOU et al., 2017). The great rainy season extends from March to mid-July to cope with the short dry season, which lasts from September to October. As for the great dry season, it begins in November and ends in March, interspersed by an unstable period of harmattan. The region possesses two types of vegetation: grassy savannah in the west and degraded forest in the east, north, and south. It is crossed by two principal rivers, "Comoe" and "N'zi," which are permanent regimes. The others are seasonal. We can quote "Ifou," the region's name. The potential economy is focused on the itinerant type of agriculture. This kind of agriculture has caused the reduction of the forest, giving way to many fallows. The most common crops cultivated are cash crops (coffee, cocoa, rubber, palm, cashew, etc.) combined with food crops (yam, cassava, etc.).

Figure 7: Trend of precipitation in the Iffou region from 1960 to 2021



Source: author compilation with world bank data

Figure 8: Trend of Temperature in the Iffou region from 1960 to 2021



Source: author compilation with World Bank data

2.4.2 Data source and sampling procedure

The data used for this study is primary data based on household surveys conducted in trays ecosystems. In this ecosystem, a two-round survey was conducted. The first was to test the questionnaire to improve its quality, and the second officially collected the information needed to do the study. The sample size was determined using the Cochran equation that is:

$n_0 = \frac{Z^2 PQ}{e^2}$ Where n_o is the sample size, z is the z-score equal to 1.96 with 95 percent confidence level, P is the population proportion set at 0.5, Q is equal to 1-P, and e is the desired margin error equal to 0.05 (Agresti & Finlay, 2009). The minimum sample size is 384. However, to increase the quality of the study, 780 farmers were invited for interviews in the trays ecosystem. A multi-stage sampling procedure has been employed to obtain the data. Firstly, the trays ecosystem was purposively selected because it is severely affected by land degradation. Secondly, eight villages in the ecosystem were chosen randomly. Thirdly, the farmers' respondents were randomly selected using a simple random technique. The data include some socioeconomic (level of education, age, gender of the household), climate data (temperature and precipitation), and institutional characteristics data (land tenure, credit access).

Table 4: The sample size in the Trays ecosystem

Ecosystem	Region	Name of village	Farmer sampled	Total population	Total farmer sampled
Trays	Iffou	Adikankro	68	845	780
		Koffie Kpri	75	1043	
		Famienkro	120	2590	
		Koffi Amonkro	130	2500	
		Nafana	113	1598	
		Tetesi	97	1056	
		Ahouan Debarcadere	85	1000	
		Koffi-Akakro	92	1447	

Source: author compilation

2.4.3 Model specification

This study is guided by the Economic of Land Degradation conceptual framework presented by Nkonya et al. (2016) which classifies the drivers of land degradation into two categories (proximate and underlying). Biophysical factors like precipitation, temperature are classified as proximate drivers. Whereas land tenure, agricultural activities, deforestation, pesticide use and slope are classifying as underlying drivers. To investigate the relationship between the dependent (land degradation) and the explanatory variables, Logistic regression has been used in this study. It is used to achieve the general objective of this work and deal with the specific objective. Its choice is because after running the normality test, the results showed us that the error terms don't follow the normal distribution. So, using linear regression or probit will bias the results. Unlike linear probability model, logit model guarantee that the estimated probabilities increase but never step outside the 0 – 1 interval and the relationship between probability (Pi) and explanatory variables (Xi) are nonlinear (Greene, 2003). In logistic regression, many of the basic assumptions of linear regression models based on the ordinary least squares method are not required, particularly the linearity of the relationship between the dependent and independent variables, the normality of the error distribution, the homoscedasticity of the errors, and the measurement level of the independent variables (Park, 2013). Also, large sample sizes are required for logistic regression to provide sufficient numbers in both categories of the outcome variable. With small sample sizes, the Hosmer–Lemeshow test has low power and is unlikely to detect subtle deviations from the logistic model. Hosmer and Lemeshow recommend sample sizes greater than 400 (Park, 2013).

According to Kirui & Mirzabaev (2015), the choice to use the Logit regression model is informed by the nature of the assessment and the kind of data available. The Logit model can be easily applied in cases where the dependent variable is categorical, nominal or ordinal, and the cases with two or more levels. Theoretically, the model can be specified as follows:

$$Y_i = \beta X_i + u_i \quad (1)$$

Where Y_i is a dummy variable that takes the value 1 or 0. In this study, Y is 1 if the land is degraded and 0 if not or improved. X_i is a vector of exogenous factors that influences Y, β are unknown parameters, and u_i is an error term. The probability that land falls under one of Y is given as:

$$(Y = 1|X) = (X, \beta) \quad (2)$$

$$(Y = 0|X) = 1 - (X, \beta) \quad (3)$$

The logistic function can therefore be defined as:

$$(Y = 1|X) = e^{X'} = \Phi\ (X'\beta),\ 1 + e^{X'} \quad (4)$$

Where Φ denotes the cumulative logistic function. Given this formulation, the equation is given as follows:

$$LD_i = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} X_i + u_i \quad (5)$$

Where LD is land degradation, and Xi represents the independent variables used in the study.

Xi is a set of variables including climate, demographic, socioeconomic and institutional characteristics factors. u_i denotes the error term. Table 5 summarizes and defines the variables used in the study.

Table 5: Definition of all variables used in the model

Variables	Description
Dependent variable	
LD	Land degradation takes 1 if the land of the farmer is degraded; 0 otherwise
Independent variables	
Age	Age of respondent in year.
Gender	Gender of the farmer; 1 male, 0 otherwise
Education	Literacy of the respondent; 1 if the respondent is literate, 0 otherwise
Hhsize	Number of people in the household

Erosion	Erosion of soil; 1 if the farmer constated erosion of soil in his plot, 0 otherwise
Pesticid	Pesticide use; 1 if the farmer use pesticide in the plot, 0 otherwise
Slope	Slope of the plot; 1 if the field is on slope, 0 otherwise
Agriact	Agricultural activity; 1 if the farmer perceives agricultural activities as responsible for LD, 0 otherwise
Defor	Deforestation; 1 if farmer perceives Deforestation as responsible for LD
Temp	Temperature in (^{o}c)
Preci	Precipitation in (mm)

Source: author

2.4.3.1 Dependent variable

The dependent variable is Ldi. It is a dummy variable that takes 0 or 1 depending on the farmer's perception. Our analysis focuses on farmer perception and expert analysis (laboratory analysis of soil sample) because the proxy of land degradation (NDVI) used by many authors doesn't really reveal if land is degraded. NDVI is the most popular index used for vegetation assessment, but according to Le et al. (2014), it has some limitations as a proxy for land degradation. One limit is that a decline in vegetation is not necessarily related to land degradation, and an increase in vegetation is not necessarily associated with an improvement of land. Another limitation is that NDVI does not tell us anything about the kind of land degradation or improvement. Also, to corroborate the assumption that NDVI doesn't reflect whether the land is degraded, some farmers have testified that the land close to their farm can be good, and the land after those mentioned above can be poor. According to Bai et al. (2008), using the raw values of NDVI as a proxy for land degradation may be biased by the factors such as rainfall dynamics. One definition of land degradation is a loss in land productivity (Blaikie and Brookfield 1987, as cited in Stroosnijder, 2007). Thus, one possible proxy for land degradation is the productivity decline of the land. Focusing on this fact, farmers' perception of the state of their land associated with expert opinions is our proxy for land degradation in this study.

From farmers' perception, the production trend over five years of their land is used to see if the production is improved. Land degradation occurs when the production trend decreases during a favorable climate (moderate precipitation and temperature). Concerning the expert opinion, they based their responses on the soil organic matter, cationic exchange capacity of the soil and the pH of the soil. According to them, the cationic exchange capacity (CEC) also indicates soil fertility. The higher the CEC, the more cations it can retain in the soil (Ca^{2+}) and improve the soil's structure or feed plants (NH^{4+}). The soil sample analyzed by experts helps them have the soil organic matter and the pH and to say if the soil is degraded. The association of the expert opinions and farmers' perceptions helps us to know if the soil of the farmer surveyed is degraded.

Whether or not land degradation is determined by climate, demographic, socioeconomic, and institutional characteristics factors, some of these variables were treated as explanatory or independent variables in this study (Table 5).

2.4.3.2 Independent variables

Land degradation models include several explanatory variables based on the empirical literature review, the economic theory, and the data availability. It included binary and continuous variables (O. Kirui & Mirzabaev, 2015; Saguye, 2017). The description of all variables is presented in table 5 and below.

Climate factors

The relevant climate factors included in this study are precipitation and temperature. Adequate precipitation and optimal temperature are needed and hypothesized to reduce land degradation. When precipitation is low or insignificant, it accelerates land degradation (Wale & Dejenie, 2013). Beyond a threshold, precipitation is assumed to cause erosion of soil, while the temperature is supposed to cause disorganization of the structure of the soil, leading to the degradation of the land (Kalisa et al., 2019).

Demographic factors

Demographic factors such as age, gender, and education are considered in our study. They have been found to affect land degradation. Higher education is assumed to reduce land degradation (O. Kirui & Mirzabaev, 2015) because it is associated with a higher understanding of the land degradation problem and SLM practice adoption (Babalola & Olayemi, 2014; O. Kirui & Mirzabaev, 2015; Teklewold et al., 2013). Education takes the value 1 if the farmer did at least six years in primary school necessary to know how to write and understand what they read and write. Household size is a continuous variable and is assumed to positively or negatively affect land degradation. According to Belay & Bewket (2013), household size can reduce or increase land degradation by the adoption of sustainable land management on the one hand and by the diversion of labor to off-farm activities on the other land.

Age is a continuous variable in this study. Age is hypothesized to positively or negatively affect land degradation. According to the literature, older farmers have a shorter time to planning horizon than younger ones. They are less likely to take care of their land or adopt some SLM practices (Saguye, 2017).

Gender is assumed to have a negative effect on land degradation. The value 1 is assigned to the male farmer and 0 otherwise.

Attitudinal factors

Attitudinal factors have been found to exacerbate land degradation. They are based on farmers' perceptions, and all are dummies variables. There are agricultural activities and deforestation. A value of 1 was attributed to a farmer who perceives each attitudinal factor as responsible for land degradation.

Plots characteristics

Relevant plot characteristics identified from literature that influence land degradation include plot size, plot tenure, distance from the plot to the markets, distance from the plot to the village, soil quality, slope, etc. In this study, only erosion, slope, and pesticide use were considered, and they are hypothesized to negatively or positively impact land degradation. The first two variables (erosion and slope) are based on the farmer's perception, and value 1 was assigned to all farmers who stated facing erosion or having their field on a slope. About pesticides, it is to know if the farmers applied them in their fields or not. If it is the case, a value of 1 is attributed to this farmer, 0 otherwise.

2.5 Results and discussion

2.5.1 Descriptive statistics

This subsection discusses the results of the descriptive statistics. Table 6 points out the mean and standard deviation results of the variables used in the regression model. The observed results reveal that men were more implicated in agriculture than women. Of the farmers interviewed, about 65% were men, while the remaining 35% were women. Also, the mean farmers' educated was 33%, while the average age of farmers was 49 years. The mean household size is estimated at 7.42 (around 8) people showing that this ecosystem is densely populated, exacerbating pressure on land.

Focusing on plot characteristics, plots on slope accounted for approximately 11.2%. Land degradation, according to farmers interviewed, is estimated at 52.4%. This high rate of land degradation is because the trays ecosystem was considered since its independence as the basin of cocoa production. It is why land is degraded in this ecosystem.

Regarding erosion, the proportion of farmers facing soil erosion in their plots was about 41%. According to them, deforestation is the leading cause of soil erosion; above all, the scarce rainfall can fall during some days creating floods that are harmful to land. For pesticide use, herbicides were mainly used because farmers had no money to hire labor. According to them, the cost of one labor per day was around 2000fcfa. Around 39% of farmers have used pesticides in their fields to fire grass to clean them. According to climate change characteristics, the average temperature is about 26°C, while for the precipitation, it was around 23 mm. The scarcity of precipitation and the high temperature play an essential role in the decision of farmers to have off-farm employment. For agricultural activities, 65% of the farmers stated that agricultural activities are responsible for land degradation and deforestation accounted for 72%, according to farmers interviewed

Table 6: Descriptive statistics of all variables used in the study

Variable	Mean	Std. Dev.	Min	Max
LD	0.524	0.5	0	1
GENDER	0.646	0.478	0	1
AGE	49.221	13.625	20	91
EDUCATION	0.327	0.469	0	1
HHSIZE	7.423	3.648	1	25
SLOPE	0.112	0.315	0	1
EROSION	0.409	0.492	0	1
PESTICID	0.387	0.487	0	1
AGRIACT	0.65	0.477	0	1
DEFOR	0.721	0.449	0	1
TEMP	26.464	0.114	26.368	26.768
PRECI	22.846	2.634	13.310	29.2032

Source: author compilation

2.5.2 Logistic regression results

The logistic regression model addresses the study's objective to identify the drivers of land degradation in the study area. Table 7 presents the results of Logit regression for the study area. The model is globally significant because the log-likelihood value was statistically significant at

1% level of significance, indicating that the hypothesis that all the coefficients except the intercept are equal to zero was rejected [(Trays: $Chi^2(11)= 75.20$, Prob=0.000)].

Table 7: Results of the logit regression

LD	Odds Ratio	Std. Err.	P>z	dy/dx
GENDER	0.265	0.06	0	**-0.314*** **
AGE	0.998	0.006	0.722	-0.001
EDUCATION	0.695	0.124	0.042	**-0.091** **
HHSIZE	1.014	0.021	0.513	0.003
SLOPE	2.642	0.69	0	**0.225*** **
EROSION	1.399	0.236	0.046	**0.083** **
PESTICID	1.308	0.209	0.093	**0.067* **
AGRIACT	1.978	0.461	0.003	**0.169*** **
DEFOR	1.575	0.277	0.01	**0.113*** **
TEMP	1.236	0.062	0	**0.053*** **
PRECI	1.01	0.008	0.202	0.002
_cons	0.004	0.006	0	

***, **, and * denotes significance at 1%, 5% and 10% respectively.
The dependent variable – LD is binary (1=degraded, 0=otherwise)

Source: Author compilation

Concerning the validation tests of the model, we used the prediction power test, the discriminating power test: the ROC curve, and the Hosmer-Lemeshow goodness of fit test. Table 8 summarizes the validation Tests. The fit test of the model to the data is good because the following Prob > chi2 = 0.4754 is greater than the pvalue=5%; the model is performant to data in our study. The predictive power of the model is perfect in the study area. The percentage obtained after running the test was estimated at 60.51%, showing that the logit model is correctly classified. The ROC[12] (Receiver Operating Characteristic) curve concerning the discrimination test power is low because the value (0.66) is comprised of 0.6 to 0.7.

Table 8: Validation tests

Hosmer-Lemeshow goodness of fit test	Prob>Chi2=0.4754
Predictive Power test	Percentage:60.51%
The discriminating power test	0.66

[12] To know more about ROC curve go to https://www.kjronline.org/pdf/10.3348/kjr.2004.5.1.11

In addition, the Variance inflation factor (VIF), which detects multicollinearity in a set of variables, has shown that there is no multicollinearity because all values of VIF(<2) were under the value "5" (Becker et al., 2014) (see table 9).

Table 9: Result of the VIF test

Variable	VIF	1/VIF
AGRIACT	1.98	0.504869
SEX	1.81	0.552731
AGE	1.24	0.805741
EDUCATION	1.23	0.815568
EROSION	1.19	0.839748
TEMP	1.14	0.879198
DEFOR	1.07	0.931457
PRECI	1.07	0.93551
PESTICID	1.06	0.938997
SLOPE	1.06	0.939241
HHSIZE	1.05	0.95662
Mean VIF	1.26	

The robust tests check conducted include the Ramsey test for omitted variables, Breuch pagan test for autocorrelation. The result of binary logit regression shows that 8 out of 11 variables in the model significantly affect land degradation in the study area (table 7). These are gender, education, slope, erosion, pesticides, and temperature. Apart from gender and education, which negatively affect land degradation respectively at 1% and 5% level of confidence, slope, agricultural activity, deforestation, and temperature positively affect land degradation at 1%, while erosion and pesticide use positively influence it at 5% and 10% level of confidence respectively. As mentioned above, our interest variable, "temperature", positively affects land degradation. For instance, an increase in the daily temperature of 1% may increase land degradation by 5.3%, holding other factors constant. This finding is consistent with Jiang et al. (2019); Kalisa et al. (2019); Kirui & Mirzabaev (2015); Safriel & Adeel, (2005); Vu et al. (2014), who argued that increasing temperature accelerates land degradation. The hypothesis on which this study is focused, the decreasing precipitation and/or the increasing temperature lead to land degradation, is verified.

Conversely to our finding, Berdimbetov et al. (2021) found that increasing temperature negatively influenced land degradation. The variable gender, which takes 1 if the farmer is a male and 0 otherwise, is less likely to experience land degradation. Indeed, keeping the other factors constant, an increase of 1 unit of the farmer who is man reduce land degradation by 0.314 unit. It is consistent with Gebreselassie et al. (2013). They argued that cultural and social setups dictate access to control land and external inputs (fertilizers and seeds), and their controls are considered discriminatory against women. Therefore, male farmers are more likely to take care of their land by investing in SLM practices than females.

Education influences land degradation negatively and significantly at 5% level of significance. It implies that an increase of 1% of educated farmers may decrease land degradation by 9%, keeping other factors constant. The explanation is that educated farmers can obtain, interpret, and respond to new information about sustainable land management practices. The result is in line with Jerop et al. (2018); Kirui & Mirzabaev (2015); Saguye (2017); Toma et al. (2017).

The slope had a positive and significant influence on land degradation. An increase of slope of 1% accentuates land degradation by 22.5%, keeping the other variables constant. This could be explained by the fact that the plot on the slope is more vulnerable to soil erosion than other flat plots. This result agrees with Leta & Iticha, (2018), who pointed out that the plot on the slope and the nature of tillage practices create a suitable condition for soil erosion. Other studies found a positive influence of slope on land degradation Martins et al. (2022); Vu et al. (2014).

Erosion has a positive influence on land degradation and was significant at less than 5% level of significance. Holding other variables in the model constant, a change in erosion by 1% will increase land degradation by 8.3%. The results found by Kangalawe (2012) corroborated our findings.

Consistent with the findings of Vu et al. (2014), agricultural activity had a positive and significant influence on land degradation at 1% significance level. It means that when agricultural activity increases by 1%, land degradation could increase by 16.9%, keeping the other regressors in the model constant. One explanation could be the way land is used and the inputs used on it. The positive and significant influence of agricultural activity on land degradation is in line with the findings of Dimobe et al. (2015).

Another variable playing a positive and significant influence on land degradation is deforestation, and it is significant at 1 percent. The positive influence implies that when deforestation increase by 1%, land degradation could be increased by 11.3%, all other things being equal. This is because deforestation reduces groundwater recharge and nutrient cycling, leads to desertification, and directly links to soil erosion.

2.6 Conclusion and recommendations

Land degradation is a severe threat to developing countries, particularly in Sub-Saharan Africa, because their economy mainly focuses on agriculture. It is an important subject due to the increasing causes and consequences. This study used surveys from farmers in the trays ecosystem and applied the binary logit regression method to analyze and identify the drivers of land degradation in this ecosystem. Descriptive data analysis showed that, on average, 52% of farmers had faced land degradation in their fields. The results obtained from the binary logit regression reveal that land degradation is significantly influenced by gender, education, plot on slope, erosion, pesticide, agricultural activity, deforestation, and temperature. Thus, the hypothesis we formulated in this study states that decreasing precipitation and/or increasing temperature lead to land degradation is verified. The diversity of the drivers of land degradation across the trays ecosystem is due to economic, social, cultural, and political differences. Thus, the problem of land degradation must be treated in holistic ways if the country wants to continue to take advantage of the agricultural sector. Therefore, immediate actions are required to reverse the negative trend of land degradation, particularly in the study areas where land degradation increases. Improving farm management skills and making information available on SLM practices could help farmers who are already suffering from the consequences of land degradation to improve their land management. Also, the government must implement some policies to curb deforestation and reduce pesticide use. For example, the government can increase the protected area and intensify patrol in them to deter illegal exploitation, raising awareness among the population about the benefits of forests and protected areas and the negative effect of pesticide use on land in the long run.

This study that mainly analyzed and identified the drivers of land degradation in trays ecosystems may still not be adequate to explain the exhaustive land degradation in the country. Future research must attempt to analyze and identify the drivers of land degradation in all the country's ecosystems to have a better overview of the drivers of land degradation.

3.0 CHAPTER THREE: ECONOMIC IMPACTS OF LAND DEGRADATION ON FARMING INCOMES IN THE TRAYS ECOSYSTEM IN IVORY COAST

3.1 Introduction

Land degradation is one of the significant issues facing Sub-Saharan African countries, particularly in Ivory coast, where the agricultural sector accounts for 23% of the total GDP (World Bank, 2019a). Land degradation is defined as "a negative trend in land conditions caused by direct or indirect human-induced processes, including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following aspects: biological productivity, ecological integrity, or value to humans" (IPCC, 2019a).

Several variables like rainfall, temperature, wind and water erosion, land management practices, soil characteristics, topography, and land use contribute to land degradation (Olsson et al., 2019). According to Kouassi et al. (2021), land degradation continues to increase in the country because of inappropriate input application and the short fallow period. For Sutton et al. (2016), land degradation results from the mismanagement of natural capital such as soils, water, vegetation, etc. It involves reduced productivity of affected lands (Olsson et al., 2019). This reduction in the productivity of affected lands provides a measure of the production equivalent to degradation (Gretton & Salma, 1996), reduces the net agricultural profit of farmers (Mirzabaev et al., 2018) and the cost of living for the farmers (Barbier & Di Falco, 2021).

In developing countries, especially in Côte d'Ivoire, agriculture plays an important role in the economy. The country's economy depends on coffee, cocoa, rubber, cotton, and palm production and exportation. More than two-thirds of the rural population are farmers, and the agricultural sector generates 66 % of export revenues. Also, Côte d'Ivoire's location allows the country to benefit from a good climate that helps it to grow a wide range of crops. Its location enables the country to become the world's largest cocoa producer. Cocoa accounts for 44 % of the total exports from Ivory Coast. Cocoa production represents 5 percent of agricultural GDP and remains the most important source of income for the farmers in the country. Apart from cocoa, cash crops such as coffee and cashew, respectively, represent 4 percent and 3 percent of exports (FAO & ICRISAT, 2018). Concerning food crops, the country benefits from a wide range of crops to achieve food self-sufficiency and solve food insecurity issues. The main staple crop production volumes are yam, rice, plantain, and cassava. Also, the population in the country is estimated at 29,389,150 inhabitants. However, the country is faced with increasingly degraded land. Indeed, 11 percent of its territory, around 3,547,093 ha of soil, were degraded from 2000 to 2010 and the lands presenting a net productivity decrease are estimated at arround 1,607,454 hectares (5 percent of arable land). The forest cover has been reduced by 4.21 percent, corresponding to a loss of 1,360,000 hectares (MINSEDD, 2017). Jones et al. (2013) have assessed the soil nutrient loss of land degradation in Africa and have found that Ivory Coast is classified among the countries with high soil nutrient loss. Outdated farming techniques, limited literacy levels, climate change, and poverty exacerbate land degradation in the country.

As a consequence, we have a reduction in the farmer's income through low productivity that increases the poverty rate, the reduction of clean water availability, migration, food insecurity, the prevalence of invasive species, biodiversity loss, and conflict because of the scarcity of fertile land (Abdeta & Geleto, 2018). Seeking to address land degradation, the Ivorian government has implemented land degradation neutrality policies. He has led an elaborate National Plan to combat land degradation aligned with the ten-year framework (2008 – 2018) of the United Nations Convention to Combat Desertification (UNCCD). To this must be added the ratification of laws and strategies in the fight against land degradation and its adhesion to the "Land Degradation Neutrality" program initiated by the UNCCD. All these commitments and adopted policies are susceptible to leading to sustainable land management in the country to improve the well-being of the farmers and increase the benefit drawn from agriculture.

Despite the effort made by the government to reverse the negative trend of land degradation, the adoption of sustainable land management remains low in the country. At the international level, some attempts have been made concerning the economic cost of land degradation in agriculture. Only a few studies deal with the economic impact of land degradation on farmer income.

Salvati & Carlucci (2013), to estimate the potential costs of land degradation in agriculture in Italy, focused on environmental sensitivity areas (ESA) which is an indirect procedure to assess changes in land reserves caused by land degradation. ESA Index simulates the environmental conditions where land is affected by serious land degradation processes and soil fertility is drastically reduced (Lavado Contador et al. 2009, as cited in Salvati & Carlucci, 2013). Mirzabaev et al. (2018) have used the remotely sensed Normalized Difference Vegetation Index (NDVI) to estimate the loss of the net farming profit in Central Asia. NDVI, used as a proxy for land degradation, doesn't really reveal whether the land is degraded. According to Le et al. (2014), it has some limitations as a proxy for land degradation. One limit is that a decline in vegetation is not necessarily related to land degradation, and an increase in vegetation is not necessarily associated with an improvement of land. Also, to corroborate the fact that NDVI doesn't reflect whether the land is degraded, some farmers have testified during our survey that the land close to their farm can be good, and the land after those mentioned above can be poor. For Bai et al. (2008), using the raw values of NDVI as a proxy for land degradation may be biased by the factors such as rainfall dynamics.

One definition of land degradation is a loss in land productivity (Blaikie and Brookfield 1987, as cited in Stroosnijder, 2007). The loss in land productivity can be caused by many factors, such as the weather, how farmers use land, and the organic matter in the soil. According to Johnston et al. (2009), soil organic matter is a key component of soil fertility and crop productivity, so attempting to evaluate the net income loss by farmers without using the soil organic matter may bias the results. Therefore, this study uses soil organic matter as the land fertility measure. In this regard, this study tries to fill the gap by combining detailed surveys of farming households in Trays ecosystem in Cote d'Ivoire with plot-level soil sampling data collected from each surveyed farm to do the economic impact analysis to ensure comparability across studies. To better understand the negative role of land degradation on the farmer's well-being, the following research question is asked: "what is the economic impact of land degradation on the farmer's income in the trays ecosystem?" To answer this question, the objective we set out is to evaluate net farmers' income reduction due to land degradation. Specifically, it is to estimate the net income loss by farmers due to land degradation focusing only on crop production. The hypothesis on which this study is based is that the reduction of soil organic matter is responsible for the reduction of the net income of farmers. This study is structured as follows: the next section presents the literature review. Section 3 deals with the conceptual framework, followed by a presentation of methods, data, and study area in section 4. Section 5 discusses the findings and the last section concludes the study.

3.2 Literature review

The literature review section gives an overview of the approaches used to evaluate the economic impact of land degradation and an empirical literature review.

3.2.1 Approaches to value land degradation

Economic valuation of land degradation is an important tool that can help to evaluate the extent and scope of land degradation (ELD Initiative & UNEP, 2015). It results in both on-site and off-site assessments, according to the literature. Two major methods used to estimate on-site economic costs of land degradation are the replacement cost approach and the productivity change approach (Sharma & Chopra, 2018; Yesuf et al., 2005). Concerning off-site costs, the methods used in the literature include contingent valuation methods, choice experiments, hedonic pricing, damage cost approach, replacement cost approach, and the benefit-transfer cost approach (Sharma & Chopra, 2018).

3.2.1.1 Approaches to determine on-site costs of land degradation

On-site costs are directly related to the land where the degradation occurs. They reduce the income obtained by land users through lower productivity due to land degradation (Low, 2013). The on-site costs of land degradation were estimated based on the loss of soil, nutrient, organic matter, productivity, and yield (Telles et al., 2011). The two leading approaches used to determine the on-site cost of land degradation are the replacement cost approach and the productivity change approach (Low, 2013).

- **The replacement cost approach**

The replacement cost approach assesses the impact of land degradation by calculating the extra cost of chemical fertilizers used to replace, maintain, or repair soil nutrients lost due to land degradation (Sharma & Chopra, 2018; Yesuf et al., 2005). The logic behind this approach is to measure nutrient loss and assign a value to it by comparing it to the cost of commercial fertilizer (Bojö, 1996). This approach implies the complete replacement of chemical fertilizer for the loss of soil nutrients and zero degradation (Nkonya et al., 2011). The replacement cost includes five steps. The first step is estimating the average rate of soil loss per hectare in different cropland areas using the Universal Soil Loss Equation. Then, the second step is to estimate the associated nutrient losses using regression. The third step evaluates the nutrient loss per hectare by considering the cost of commercial fertilizer replacement. Step four focuses on the estimation at the national level of areas subject to erosion. The last step consists of deducting the gross losses in national income (Bojö, 1996). The replacement cost approach has some limitations. It is not a perfect substitute for soil fertility. It does not always represent the opportunity costs of degraded soil because the cost of additional fertilizer applied does not account for the value of lost organic components of the soil. This approach could understate the topsoil loss value while overestimating soil loss nutrients (Bojö, 1996). According to Yesuf et al. (2005), the replacement cost does not reflect the opportunity cost of degraded land because soil erosion affects nutrients, organic matter content, and the soil's physical structure. Also, attributed soil nutrients as the most limiting factor in crop production can be biased, and fertilizer application is not likely the best cost-effective option for farmers to maintain production. Another limitation of the replacement cost is that it is a cost measure to avoid or mitigate land degradation but not a measure of the cost of allowing land degradation (Yesuf et al., 2005).

- **The productivity change approach or loss of production**

The productivity change approach measures the direct cost of land degradation (Sharma & Chopra, 2018) and relies on projected crop yields with and without soil erosion (Yesuf et al., 2005). It estimates the amount of soil loss and converts it into a reduction in crop production (Low, 2013). According to this approach, the value of degraded land equals the value of crop production loss valued at market prices. The productivity change approach is simple and direct, but the challenge is to find appropriate reference productivity to compare or establish a counterfactual. For Yesuf et al. (2005), the productivity change approach is logical and straightforward to apply. However, it requires information about production and the processes of degraded land. Also, it requires information on how the specific nature of land degradation affects production. Like the previous approach, the productivity change approach has some limits. It compares the decrease in yield to a hypothetical benchmark of non-degraded soil without knowing the production where the soil is not degraded (Yesuf et al., 2005). Another limitation of this approach is that the measure of production loss is not a true reflection of the current cost of degraded land because some types of degradation occur due to more productive farming systems (Gretton & Salma, 1996). The productivity change approach does not consider the degradation that occurs when farming systems become more specialized. However, the productivity change approach has been used in different ways. Agroecological and soil erosion models, field-based experiments, analysis of sediment loads, and plots are some ways to estimate productivity loss in physical terms.

In summary, compared to the replacement cost, the productivity change approach is more appealing in evaluating the on-site costs of land degradation despite its limitations.

3.2.1.2 Approaches to determine off-site economic costs

Off-site economic costs are costs outside the area where land degradation occurs. Land degradation leads to several off-site impacts, establishing costs for people far from the site (Sharma & Chopra, 2018). Most off-site cost estimates for land degradation are based on sedimentation calculated using the USLE and the amount of sediment reaching water bodies (Telles et al., 2011). Diverse approaches have been used in the literature to assess off-site costs. These are contingent valuation methods, choice experiments, hedonic pricing, damage cost approach, and benefit-transfer cost approach. However, the challenge of assessing off-site impact is the lack of data on biophysical aspects and the lack of information about market prices for environmental goods (Low, 2013), and the lack of a comprehensive conceptual framework that would clearly define the variety of off-site costs (Berry et al., 2003).

- **Contingent valuation methods (CVM)**

CVM is a stated preference approach that relies on directly asking or eliciting people's value for nonmarketed benefits. Contingent valuation method is based on a survey or questionnaire conducted face-to-face, by telephone, or by mail to ask a respondent their willingness to pay (WTP) for an environmental improvement or their willingness to accept (WTA) compensation for a loss or degradation of environmental assets or quality to evaluate non-market goods and services (Rahim, 2008). CVM estimates the economic values of different ecosystems and environmental services and is the most popular method to evaluate non-use and use values (Nautiyal & Goel, 2021). It describes the ecosystem service to be valued and considers the willingness to pay of people for a specific environmental service (ELD Initiative & UNEP, 2015). In this method, the monetary value of non-marketed goods and services is assessed using the stated values of the people's responses (Sharma & Chopra, 2018). The contingent valuation method requires knowledge of survey design and econometrics. It can estimate the total change in an environmental good and service (Petcharat et al., 2020). Also, to realize it, it is important to know the good or service to be valued and who will benefit from it (Sajise et al., 2021). This method suffers from some biases. It may overstate or understate the monetary value of the ecosystem goods and services from land.

- **Hedonic pricing**

Derive from the characteristics theory of value developed by Lancaster (1968), Griliches(1971) and Rosen (1974), the hedonic pricing identifies environmental services flows as element of the vector of characteristics describing a marketed good. It seeks to find a relationship between the level of environmental services and the price of marketed goods.

Hedonic pricing uses market prices in terms of property or rental values to determine the value of ecosystem goods and services (Sharma & Chopra, 2018). It is based on the consumer theory that each good provides a bundle of characteristics or attributes (ELD Initiative & UNEP, 2015) and assumes that the differences in market values are attributable to the different levels of land degradation (Sharma & Chopra, 2018). Hedonic pricing depends on observable data from people's actual behavior (Rahim, 2008). It is used to estimate economic benefits or associated costs with environmental quality such as air, water, and noise pollution; environmental amenities. It is often used to value environmental that affect the residential properties' prices and can take into account a variety of interactions between market goods and environmental quality. However, when land markets are imperfect, or there is asymmetric information on the cost and benefit of land productive capacity, this method overstates and understates the values of goods and services.

- **Choice experiment**

Initially developped by Louviere and Hensher (1982) and Woodworth (1983) in the marketing economics and transportation literature, Choix experiment has been applied in environmental economics to valuate non-marketed environmental goods (Sukanya, 2014). It is close to the contingent valuation method and asks to choose the most preferred option from a set of proposed options with varied attributes and explicitly defines the characteristics of the ecosystem services. Its goal is to estimate the economic values of environmental good characteristics or attributes subject to policy analysis (Holmes et al., 2017). For this approach, the willingness to pay response for change in attributes obtained from the respondents is used to evaluate the ecosystem good or service. The advantage of this method is that it can assess multidimensional environmental changes (Pearce et al., 2006). According to Holmes et al. (2017), choice experiments can provide values for changes in a single characteristic, levels of characteristics, or multiple changes in characteristics, resulting in a response surface of values rather than a single value. For Koemle &

Yu (2020), choix experiment assures the unbiased and uncorrelated distribution of attributes and levels among choice sets, and therefore significantly impacts the consistency and efficiency of estimated parameters. One of the limit of this method is the biases it is subject to estimate the proper values of the good or service (Sharma & Chopra, 2018). Also, it associates multiple complex choices between a set of bundles with many attributes and levels

- **Avoided cost or damage cost approach**

Avoided cost is the cost that would have been incurred in the absence of ecosystem services. According to ELD Initiative (2019), avoided cost estimates the economic value of ecosystem services based on either the cost of avoiding damages from lost services or replacing them. It assesses the cost of degradation or conservation benefits by estimating the cost of damage that could have been avoided if the degradation had not occurred. Also, it uses the value of the protected property or the cost of action taken to avoid damages as a measure of the benefits provided by an ecosystem. Avoided cost takes into account the cost of providing a substitute with a similar function as well as the monetary value of the ecosystem service. It can be used for the economic valuation of intermediate ecosystem services.

One limit of this approach is that avoided costs do not provide strict measures of economic values because it is based on the willingness to pay of people for a product or service. Also, this approach does not consider social preferences for ecosystem services or individual behavior in the absence of those services (ELD Initiative, 2019).

- **Benefit transfer approach**

Benefits transfer is applying valuation results gathered from one location to estimate the economic values of ecosystem services in an alternative location. It is an approach to assessing the value of ecosystem service in the presence of difficulties in conducting an original valuation study due to funding or time constraints. It can be accomplished in two ways: unit value transfer and function transfer. Unit value transfer applies per-unit value from previous studies to estimate the value of ecosystem service in the policy site. It is based on the assumption that the unit value at the study site is representative of the policy site. Concerning function transfer, it transfers a benefit function at the study site to the policy site.

Benefit transfer is a way to estimate economic values when data are lacking in the primary site. It can be used as a screening technique to examine the necessity of a more detailed study that applies valuation methods. Its application includes five steps, according to Plummer (2009). These are: identify similar research, analyze similarities, evaluate qualities, adjust the value, and estimate the total value.

Like its predecessors, benefits transfer has several limits to producing reliable outcomes in value estimation. First, it isn't easy to find well-conducted primary studies Plummer (2009) that used sound valuation techniques and examined the same ecosystem services considered for the project site. Then, it is susceptible to error due to a lack of correspondence between study and policy sites. Finally, it is mainly focused on economic aspects, while social, economic, and natural science information are necessary for the value estimation study of ecosystem service.

3.2.1.3 Alternative assessment of the economic impact of land degradation

The alternative assessment of the economic impact concerns assessing the economic value of repairing or restoring land degradation (Gretton & Salma, 1996). It focuses on the cost-benefit analysis that compares the present value of the cost of some action to the present value of adopting sustainable land management practices. Its analysis relies on estimates from the above approaches to attribute the costs of land degradation. It allows for identifying whether land repairment would be socially beneficial at the national level (Yesuf et al., 2005).

Cost-benefit analysis integrates the cost of degraded land at different scales to assess the net costs to society without action to repair or restore land degradation (Low, 2013). Its application includes a set of nine steps (Verdone, 2015). According to Verdone (2015), It is to specify the set of restoration transitions, identify the stakeholders who will be impacted by restoration, list the impacts and define how they will be measured, predict the consequences quantitatively over the time horizon of the project, monetize all of the effects, reduce benefits and costs to obtain present values, compute the Present Net Value of each alternative; perform sensitivity analysis and make policy recommendations.

Like other economic valuations of changes to ecosystem services, the cost-benefit analysis application provides useful decisions for policy-makers with a sounder basis for making land-use decisions rather than looking at the direct costs of land degradation. The major challenge in conducting a cost-benefit analysis is that it is difficult to evaluate the social and environmental benefits (Wainaina et al., 2020). Cost-benefit analysis has some limitations. According to Requier-Desjardins et al. (2011), inadequate consideration is given to non-visible costs, indirect, social, and off-site degradation costs in the cost-benefit analysis computation process. For Low (2013), cost-benefit analysis does not show how the cost associated with land degradation and the benefits of SLM are distributed across stakeholders. Another limitation is that the internal rate of economic return is used to compare the economic performance of SLM techniques. Although it has some limits, it can be specified to assess the profitability of adopting conservation measures if data are available (Nkonya et al., 2011).

3.2.2 Empirical review

The economic impacts of land degradation are estimated in terms of cost. They have fluctuated over the years with differences in assessment methodologies. Most land degradation onsite cost assessments have focused on soil erosion, nutrient loss, productivity loss, and salinization. In contrast, offsite costs have based on sedimentation due to soil erosion (Sharma & Chopra, 2018). This empirical review focuses on the cost of productivity loss to understand the studies dealing with land degradation and agricultural productivity.

For example, Atis (2006) assessed Turkey's economic impact on cotton production. Using two production functions (Cobb-Douglass), one for non-degraded land and the other for degraded land, to estimate the reduction in cotton productivity, the author evaluated the reduction in cotton yield due to soil degradation at 41.4%. According to him, this reduction due to land degradation is around 34.4%, and the yield loss due to changes in input use represents 7%. Considering the estimated reduction, the loss in value was equal to $860.2/ha. This amount represented the estimate for the gross marginal reduction. These findings show the negative effect of land degradation on farmer income in the Menemen region in Turkey.

Oladeji (2007) discovered that, despite the indirect link with the land, non-agricultural income is affected by land degradation in his study conducted in Imo State, Nigeria. According to the author, land degradation reduces farmers' livelihood activities. He also found that crop planting is the one which more affected agricultural income. It was ranked 1st, following by goat rearing, local fowls and sheep rearing. Concerning non-agricultural income generating activities, collection of forest products, hired labour and petty trading are negatively affected by land degradation. They are respectively classified 1st, 2nd and 3rd.

He showed that before land degradation, farmers were more implicated in income-generating activities compared to after land degradation. For him, the difference results from the adverse effect of land degradation on the farmer's livelihood activities manifested by a change in production level.

By using the difference between the maximum environmental sensitivity area index score and the environmental sensitivity area index score measured in 1990 to quantify the initial land quality, Salvati & Carlucci (2013) found that 3% of the Italian land surface were affected by land degradation in 2000, 24% in 2006 and up to 27 % in 2015. The authors estimated the depletion factor of agricultural income due to land degradation through the user cost approach. According to the authors, land classified as high risk increased from 1.1 percent in 2000 to 4.4 percent in 2006. In 2015 the risk ranged from 2.9 to 8.6 percent, negatively affecting agricultural income. Notably, the depletion factor to agricultural income is derived from a composite index of land sensitivity to degradation.

Shevchenko et al. (2017) in their article titled "Economic assessment of land degradation and its impact on the value of land resources in Ukraine" have found that total losses from degradation processes in the soil surface can be determined by the analysis of agricultural productivity reduction and the costs of land degradation recovery. The authors have developed a formula which allow them to assess the economic losses from degraded land in the full degree in Ukraine. They have tested the fomula on an example of the model of the 5,28 ha land plot where unsustainable farming caused land degradation. They found that the landholder who has caused the development of degradation processes due to extensive farming must compensate the public loss of 365,8 thousand UAH ($13,5 thousand, USA).

Mirzabaev et al. (2018) estimated the loss in agricultural profit due to land degradation at about 27% in their study carried out in Central Asia on the impact of land degradation on agricultural profits and poverty. These losses in agricultural profits occurred during the 2009-2010 cropping season. The authors found that households in the medium and rich asset categories are the most affected by the reduction in agricultural profit due to land degradation. The losses are respectively

25%, 30%, and 34% for the households in the poor, medium, and rich asset categories. The authors used the production function approach to estimate the agricultural profit. This approach takes into account the climate, the quality of land, and socioeconomic factors. Also, the authors focused on NDVI to map the degraded land.

Measuring the Impact of Land Degradation on Agricultural Output in Volgograd Region (Russia), Makarov et al. (2021) have found that the total agricultural land productivity decline with erosion and salinity. The authors used the modified Cobb-Douglas production function and the data from the Ministry of Agriculture of the Russian Federation for agricultural and peasant farms to assess how land productivity is shifted in different types of agricultural holding (agricultural organization and peasant farmer enterprise). They showed that the southern districts, south-eastern and eastern districts (degraded land) are the most affected, with a salinized agricultural land proportion of more than 10% and a productivity of land less than 2-3 times compared to the northern and northwestern districts (non-degraded). According to the authors, land productivity in the southern, south-eastern, and eastern districts is lower. The income drawn from one ha is between 2 to 5 thousand rubles less compared to the northern and northwestern districts, where the income is between 11 to 20 thousand rubles per ha, and the land is more productive. To conclude, the authors argued that soil salinization shifts the production function by 0.01 percent and less than 1 percent in peasant farmer enterprises and agricultural organizations. This shift has a negative influence on profitability.

With microdata obtained from the Demographic and Health Survey that contains detailed georeferenced household-level information about living standards in many sub-Saharan African countries, Barbier & Di Falco (2021) have examined the relationship between land degradation and poverty in developing countries. The authors, estimating an ordered probit model, found that households with good land (higher soil moisture) have 21% probability of belonging in the highest quintile and 17 % probability in the lowest quintile of the living standard measure. More interesting, the authors found that the probability of the outcome increase when the level of soil moisture is higher.

3.2.3 Theoretical Framework

Agricultural productivity changes result from land quality (soil organic matter), labor, capital, and quantity of land (Requier-Desjardins et al., 2011) and climate (Mechiche-Alami & Abdi, 2020). Degraded land is associated with a reduction in productivity for all input levels in the production function. So, this study is guided by agricultural production theory which uses the agricultural production function to explain the maximum output that can be obtained from some inputs by the farmer (Rasmussen, 2011). The maximum output obtained helps to determine the farm income received by farmers. The agricultural production function is presented as follows:

$$y=f(x_1,x_2, z, c, som) \quad (1)$$

where y denotes the yield of crops, x_1 the inputs used in production (fertilizers, pesticides, labor, machinery, etc.), and x_2 represents the land area used for production, z is a vector of other farm characteristics, such as access to extension, closeness to markets, etc. c stand for climate variables (temperature and precipitation), and som stands for land fertility as measured by soil organic matter (SOM). According to Lewis, (1969), farmers seek to maximize their profit, using a combination of inputs to get a maximum output while minimizing their input costs. The principle is captured by equation 2:

$$\Pi= max\ \Sigma(P_x * y) - \Sigma\ P_i * I \quad (2)$$

Where Π *is the net income from the land,* P_x *is the output prices, and* **y** *is the production function.*

The change in net income ΔU resulting from land degradation from L_0 to L_1 can be measured as follows:

$$\Delta U = \Pi(som_0) - \Pi(som_n) \quad (3)$$

Where ΔU, $\Pi(som_0)$, and $\Pi(som_n)$ represent the change in the net income due to different levels of soil fertility.

$\Delta U>0$ net income obtained during the first use of land is greater than net income received during the last use.

$\Delta U<0$ net income obtained during the first use of land is lesser than net income received during the last use.

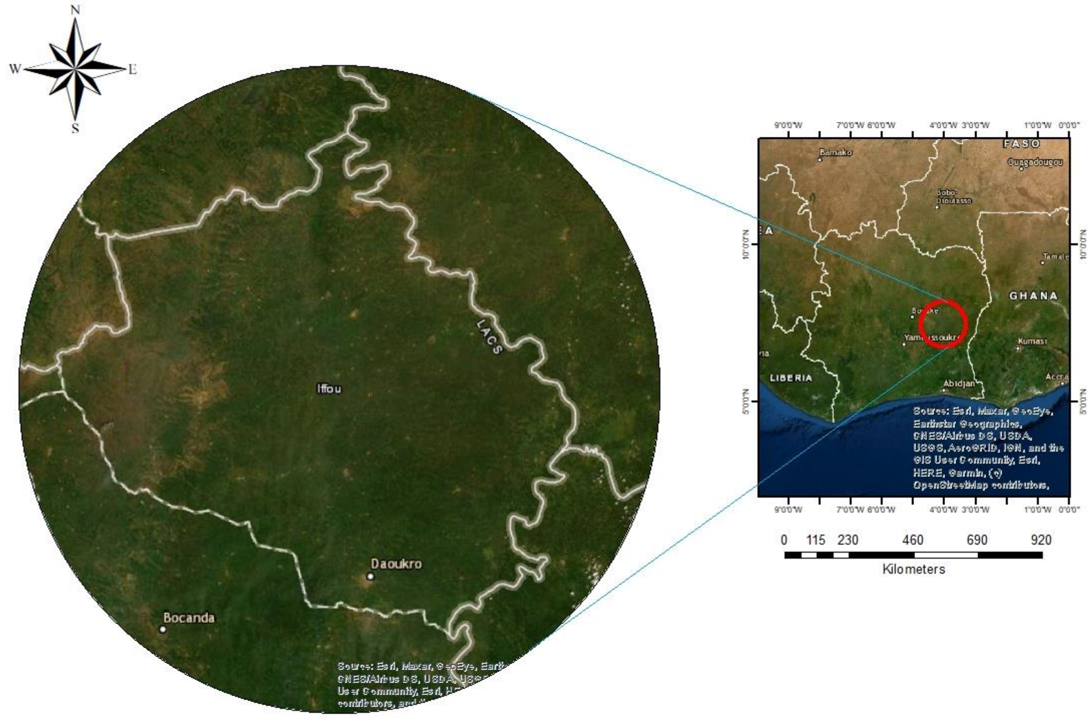
3.3 Methodology

3.3.1 Study area

The research took place in Côte d'Ivoire, a country situated in West Africa between latitudes 4°30' and 10°30' North, and longitudes 2°30' and 8°30' West, covering an area of 322,462 km2 (A. M.

Kouassi et al., 2022). The study specifically focused on the trays ecosystem, which spans the central-eastern and northern parts of the country. Within this ecosystem, our research was centered on the "Iffou region," located in the central-eastern part as depicted in Figure 9. This region was chosen due to its persistent issue of land degradation over the past two decades. Once a cocoa basin following independence, it has now experienced depopulation due to declining agricultural productivity. The Iffou region encompasses an area of 8955.05 km2, with an estimated population of 378,560 inhabitants (INS, 2021). The climate in this area is characterized as an equatorial transition regime, with hot and humid conditions and alternating between four seasons divided into two rainy and two dry seasons (KOUAKOU et al., 2017). The period of heavy rainfall, known as the great rainy season, occurs from March to mid-July, while the small dry season takes place between September and October. The great dry season starts in November and lasts until March, interrupted by an unstable period of harmattan. Within the region, two types of vegetation can be found: grassy savannah in the western part and degraded forest in the eastern, northern, and southern regions. The area is traversed by two main rivers, Comoe and N'zi, which flow consistently, while others have seasonal flow patterns. The primary focus of the local economy is extensive agriculture. Cash crops such as coffee, cocoa, rubber, palm, cashew, etc., are commonly cultivated alongside food crops like yam, cassava, rice, etc. However, this agricultural practice has led to the reduction of forests and the emergence of fallow land.

Figure 9: Study area



Realization: 2022 Source: author using ArcGIS

3.3.2 Data sources and sampling

In this research, data was collected from farmers residing in the "Iffou region" using a questionnaire. The survey was conducted in two stages. Initially, the questionnaire was tested in a small number of villages within the study area during the first stage. The feedback and information obtained from this stage were instrumental in enhancing the quality of the questionnaire. Subsequently, the second stage was conducted to officially collect the necessary information for the study. Through individual interviews, various aspects such as sociodemographic characteristics, economic activity, field number, production system, crop yield, awareness of sustainable land management (SLM) practices, farm management, and adoption of SLM practices were documented. The sample size was determined using the Cochran equation that is:

$n_0 = \frac{z^2PQ}{e^2}$ Where n_o denotes the sample size, z the z-score equal to 1.96, taking into account a confidence level estimated at 95%, P is the proportion of the population set at 0.5, Q is equal to 1-P, and the desired margin error equivalent to 0.05 is e (Uakarn et al., 2021). The minimum sample size is estimated at 384. However, to increase the quality of the study, 780 farmers were invited for interviews in the trays ecosystem (Table 10). A multi-stage sampling procedure has been employed to obtain the data. Firstly, the Iffou region was purposively selected because it is severely affected by land degradation. Secondly, eight villages were randomly selected in the region. Thirdly, the farmer respondents were randomly selected using a simple random technique. Besides these data, we have collected secondary data from the NASA[13] website. The data collected from the NASA website are the mean annual climate data (temperature and precipitation) obtained through the coordinates of the villages.

Table 10: The sample size in the Trays ecosystem

Ecosystem	Region	Name of village	Farmer sampled	Total population	Total farmer sampled
Trays	Iffou	Adikankro	68	845	780
		Koffie Kpri	75	1043	
		Famienkro	120	2590	
		Koffi Amonkro	130	2500	
		Nafana	113	1598	
		Tetesi	97	1056	
		Ahouan Debarcadere	85	1000	
		Koffi-Akakro	92	1447	

3.3.3 Empirical framework

In the empirical analysis, the reduced form estimation studying the economic impacts of land degradation on farming income is applied. In the theoretical framework, the reduced form (1) is estimated using two-stage least squares (2SLS) to overcome potential endogeneity issues with omitted variables, reverse causation or simultaneity, and measurement errors when estimating land degradation and net farming income variables. The two-stage least squares approach is used with soil organic matter as the endogenous regressor; precipitation and temperature as instrumental variables. Soil organic matter is based on the result obtained from laboratory analysis of soil samples gathered from the surveyed farmers' plots. Precipitation and Temperature (averages from 1985 to 2015 years), while influencing the accumulation of soil organic matter (SOM) – our endogenous variable, don't have a direct effect on the net farmer's income our dependent variable. The average precipitation and temperature may not directly affects the net farmer income because

[13] https://power.larc.nasa.gov/data-access-viewer/

farmers can choose crops that are suitable for prevailing climatic conditions, can mitigate the impact of low precipitation and high temperature by using irrigation, and can implement various sustainable land management practices like conservation tillage, mulching and efficient irrigation techniques to optimize water usage. They are the components that determine the potential distribution of terrestrial vegetation and constitute essential factors in soil evolution (Siva Kumar & Ndiang'ui, 2007). High temperatures accompanied by low precipitation disorganize the structure of the soil and lead to poor organic matter, which reduces its productivity. Following Cameron & Trivedi (2010), the structural equation is:

$$y_{1i} = y'_{2i}\beta_1 + x'_{1i}\beta_2 + u_i, \qquad i=1,...,N \qquad (4)$$

where u_i, the regression errors are assumed uncorrelated with x_{1i} but correlated with y_{2i}.

Equation (5) presents the first stage:

$$Y_{2ji} = x'_{1i}\alpha_{1j} + x'_{2i}\alpha_{2j} + v_{ji}, \qquad j=1,...,m \qquad (5)$$

The two-stage least square IV estimation is conducted using the "ivregress" package in Stata 16 (Cameron & Trivedi, 2010).

The reduced form model is given by equation (6):

$$\boldsymbol{Netlincom = \beta_0 SOM + \beta_1 H + \beta_2 C + \beta_3 P + \beta_4 I + U} \qquad (6)$$

Where *Netlincom* is the logarithm net income, *SOM* is the soil organic matter variable. It is a continuous and endogenous variable, *H* is the vector of household characteristics (Gender, age, education, and household size), *C* is the climate variables (temperature and precipitation), *P* is the vector of plot characteristics (farm size, plot slop, pesticide use, farm labor, and total farm), *I* is the institutional vector (advice and information, membership and property right), and *U* is the error term. Also, $\boldsymbol{\beta}$ represents the vectors of the estimated coefficients.

3.3.3.1 Description of the variables

3.3.3.1.1 Dependent variable

The dependent variable used in this study is Netlincom, which is the logarithm of net income from agricultural production alone obtained by subtracting net income from 2016 and 2020. It is obtained by multiplying the production in kg with the market price. After, we deducted the cost engaged by the farmer during the process of production. Some of the net incomes are negative. While taking the logarithm, those values of net income which are negative are suppressed. To avoid this and include those as well, we added plus 1 “one” to all data in the column of the logarithm net income. Practically, this procedure does not affect our slope coefficients (our key interest), but does affect the slope level.

3.3.3.1.2 Independent variables

Based on the economic theory, the data availability, and the literature review, twelve (12) independent variables have been chosen to carry out the regression. These variables are classified into four groups: *household characteristics, climate variables, plot characteristics, and institutional factors*. The description of these variables is presented in table 11. More explanation for the “soil organic matter”, our endogenous variable, is given below.

- Soil organic matter variable

Soil organic matter variable used in this analysis is expressed in percentage. It is based on the result obtained from soil samples taken at 15 cm depth in each field during the interview with farmers. Soil organic matter consists of decomposing plant and animal residues. The production trend of their land is used to see if the production is improved and if the soil analysis result corroborates with the outcome the farmers gave us. A soil with less than 5 percent organic matter is considered degraded, while the other with an organic matter of at least 5 percent is considered non-degraded (Londeree, n.d.). Soil organic matter consists of decomposing plant and animal residues. In high temperatures and low precipitation, soil organic matter is negatively affected. A good fraction of organic matter in the soil contributes mainly to cation exchange capacity (CEC) and color (Bot & Benites, 2005). It improves nutrient availability and is the main pool of nutrient storage (Gerke, 2022). The functions of soil organic matter are many. Among others, we can quote the creation of the granular condition of soil which maintains the favorable condition of aeration and permeability and acts as a buffering agent, preventing rapid chemical changes in pH and soil reaction.

- Gender

In agriculture, gender plays an essential role in income formation. It has two modalities (0 and 1). The value 1 is assigned to male household head farmer and 0 to woman. Both of them at a certain level play a great contribution to the farmer income formation in all developing countries. When it comes to food crops, women are usually the ones who have a positive impact on income formation because they are more involved in food production and adopt some of the sustainable land management practices (Jerop et al., 2018). Conversely, when it comes to cash crops or other activities, it is the man who has a positive impact on income formation. Okoth et al., (2023) corroborate the fact that male-headed households earn more income than females-headed-households. Indeed, women face some issues that allow men to have more income than them. They have limited land access and use higher fixed, labour input costs and seeds (Mishra et al., 2017).

Table 11: Description of the variables

Variables	Description
Dependent variable	
NETLINCOME	Logarithm net income in Fcfa; it is the difference between the net income obtained from the use of the land during 2016 and 2020.
Independent variables	
Endogenous variable	
SOM	Soil organic matter, it is expressed in %
Household characteristics	
GENDER	Gender of the respondent; 1 male, 0 otherwise
AGE	Age of the respondent in the year
HHSIZE	Number of people in the household
EDUCATION	Literacy of the respondent; 1 if the respondent is literate, 0 otherwise
Institutional Factors	
ADVINF	Advice and information about SLM; 1 if the farmer receives advice and information about SLM practices/technologies from the agent in charge of agriculture, 0 otherwise
Plot characteristics	
FSIZE	The size of the main farm in hectares
EROSION	Erosion of soil; 1 if the farmer perceived erosion in the plot, 0 otherwise
PLOTSLOP	Slope of the plot; 1 if the farmer's plot is on a slope, 0 otherwise
PESTICID	Pesticide use; 1 if the farmer uses pesticide in the plot, 0 otherwise
PROPRIGHT	Property right: 1 if the farmer has the title of his land, 0 otherwise
Climate variables	
PRECI	Precipitation, average precipitation from 1985 to 2015 in (mm)
TEMP	Temperature, the average temperature from 1985 to 2015 in (°c)

- Age

Age of the farmer is expressed in years. His effect on the net farming income is negatively established. Some authors, like Guo et al. (2015); Saguye (2017) found that elderly farmers negatively impact agriculture because they resist new practices and technologies, so their agricultural outputs are less and they have less income, compared to the younger. According to Saguye, (2017) the negative relationship between age and net farming income results from the fact that elderly farmers have a short horizon of planning than younger.

- Household size

Household size is supposed to have a mixed effect on the net farming income and is expressed in the number of people living in the household. On the one hand, larger household size may be associated with higher labour endowment which is one factor of the production in the Cobb-Douglass function. Taking the other variables constant in the Cobb-Douglass function, more the household size increase, more the output is supposed to increase allowing also the increase of the net farming income. On the other hand, larger household size may be associated with higher expenses because the amount of money spent on good and services increase. In other words, a household of a larger size may spend more on goods and services allowing the reduction of net farming income.

- Education

Education is a binary variable which takes 1 if the respondent is educated and 0 otherwise. In this study, a farmer is educated if he received at least six years of formal education. It is hypothesized to have a positive impact on the net farming income (Serin et al., 2009). Indeed, a farmer with a high level of education earns more income than a farmer without any formal education or less. This implies that school-based education skills can be applied to farming and educated farmers can more easily adopt sustainable land management practices or technologies to improve the productivity of their fields.

- Slope

Slope is a dummy variable. It is based on the farmer's perception. The value 1 was assigned to all farmers who have their fields on the slope. The effect of slope on the net farming net is undetermined. For instance, Leta & Iticha, (2018) attribute the negative effect of slope on the net farming income because the slope creates the suitable condition for soil erosion. Conversely, Martins et al. (2022); Vu et al. (2014) attribute a positive effect to the slope. For the authors, the fact that farmers are conscious that their fields are on a slope allows them to adopt some sustainable land management practices or technologies.

- Erosion

Erosion is a dummy variable focused on the farmer's perception and field observation. The value 1 is attributed to a farmer who has stated facing erosion in his field, 0 otherwise. It is hypothesized to negatively influence the net farming income because it decreases soil fertility by erasing away the top layers of the topsoil, which constitutes the area the most fertile over time. Previous studies show a negative relationship between soil erosion and net farming income (Kangalawe, 2012).

- Advice and information

Advice and information are hypothesized to have a positive influence on the net farming income. It is a dummy variable which takes 1 if the farmer receives advice and information about sustainable land management practices/technologies to improve his net income or 0 otherwise. Previous authors like Danso-Abbeam et al. (2018); Saguye (2017); Teklewold et al. (2013); Toma et al. (2017) have established positive effects of advice and information on net farming income.

- Pesticide use

The use of pesticides is a dummy variable which takes 1 if the farmer uses pesticides in his field, and 0 otherwise. It is assumed to have both (negative and positive) effects on the net farming income. In the short run, it has a positive effect on the net farming income because they protect the crop from pest destruction. Popp et al. (2013) have established a positive impact of pesticide use on net farming if they are correctly used. Conversely, if they are not used correctly, they can reduce farmers' income because of the loss of natural pollinators, ground water contamination, etc. (Pimentel et al., 1995). In the long run, the use of pesticides negatively affects the net farming income because of the accumulation of chemical matter in the soil causing its degradation.

- Property right

Assumed to positively influence the net farmer income, property right is a dummy variable taking the value 1 if the farmer has the title of his land, and 0 otherwise. Indeed, the detention of property right by farmer incentive them to invest in sustainable land management practices/technologies to improve the productivity of their fields by extension their net farming income (Heltberg, 2002; Kabubo-Mariara, 2007; O. K. Kirui & Mirzabaev, 2015; Saguye, 2017).

- Farm size

Farm size is expressed in hectares (Ha). It is supposed to be positively associated with net farming income. The positive association is established by some authors like Baidoo et al. (2017); Noack & Larsen (2019); Oduniyi & Tekana (2021) who argue that an increase in farm size is likely to increase farmers' output and hence their income.

- Precipitation

It is expressed in millimetres (mm). It is supposed to have both (positive and negative) effects on the net farming income. Beyond a certain threshold, it caused erosion of soil. When precipitation is low or insignificant, it accelerates land degradation and reduces the net farming income (Wale & Dejenie, 2013). Torres et al. (2019); Shumetie & Alemayehu, (2017) have shown the negative effect between precipitation and net farming income.

- Temperature

Temperature also is hypothesized to have both effects on farming income. It is expressed in degree Celsius (^{o}C). Beyond 32.2^{o}C threshold the effect of temperature on the net farming income is negative (Lambert, 2014; Shumetie & Alemayehu, 2017).

3.4 Results and discussion

3.4.1 Descriptive statistics

Table 12 presents the results of the descriptive statistics. Out of 780 farmers interviewed, about 65% were men, while the remaining 35% were women in the ecosystem. This result observed in the study areas reveals that men were more implicated in agriculture than women. The average age of the farmer was 49 years, and 33% of these farmers were educated (at least six years of formal education). On average, the household size of the farmers interviewed was eight (8) people. This number shows that the ecosystem is densely populated. The average area cultivated during the

2021/2022 cropping season was 2.32 hectares. This size allows us to consider the farmers in the trays ecosystem as small farmers. According to the farmers, it considers the plots used for food and cash crops.

Comparing the net income received by farmers during the year 2016 and 2020, we found that the average net income received in 2016 was estimated at 491,531 FCFA, while the net income obtained in 2020 was around 407,814 FCFA.

Table 12: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
INCOME1	491530.800	556710.900	37000	7025590
INCOME	407813.500	474429.400	20000	5700000
NETLINCOME1	1.105	0.126	0.038	2.069
SOM	5.010	1.170	2.040	8.430
GENDER	0.646	0.478	0.000	1.000
AGE	49.221	13.625	20.000	91.000
EDUCATION	0.327	0.469	0	1
HHSIZE	7.423	3.648	1	25
PLOTSLOP	0.112	0.315	0	1
EROSION	0.409	0.492	0	1
ADVINF	0.406	0.491	0	1
PESTICID	0.387	0.487	0	1
PROPRIGHT	0.408	0.492	0	1
FSIZE	2.321	2.298	1	16
FSIZESQ	10.660	27.511	1	256
PRECI	22.846	2.634	13.310	29.203
TEMP	26.464	0.114	26.368	26.768

A difference of 83,717 FCFA is observed, showing the reduction of farmer income drawn from agriculture as land is used. Thus, the average net income of the farmer decreased from 2016 to 2020.

For the institutional factors like advice and information, 41 % of the farmers have stated receive information and advice from the agricultural ministry expert at least once in the 5 last years. Progress must be done for two-thirds of the population to have extension services access. Farmers' pointed out that the advice and information about agriculture and climate change coming from the government, private companies, and non-governmental organizations are important because, with climate change, they need some advice and information that can help them face this issue. The percentage of farmers who reported having property rights in their fields is estimated at 41%.

Pesticide use was 39% in the study area, meaning that 1/3 of the farmers used pesticides. According to some farmers' explanations, the use of pesticides by farmers is because of the lack of labor force and sometimes poverty. Also, most farmers don't know that pesticides are harmful to the soil in the long run. It was found that 39% of the farmer have perceived the soil erosion problem on their farm plots. Most have disclosed using conventional practices like mulching to curb this issue. Only 11% of the farmers have stated that their farm plot is on a slope.

Like climate variables, the temperature and precipitation were respectively estimated at 26.5 ^{o}C and 23 mm on average. These values show that the study area is not well-drained and extremely hot. Concerning the soil organic matter, it is estimated at around 5%. About 48% of the farmer interviewed have disclosed that their land is degraded. Each year, their land productivity declines because of the scarcity of precipitation and the high temperature. Although their land has undergone degradation, 24% of farmers use fertilizer, and the average quantity is estimated at 2 kilograms, while 8% use improved seed. Conversely, the percentage of farmers who use pesticides is around 39%.

3.4.2 Instrumental Variables (Two-Stage Least Square) regression

The results of Instrumental variables (two-stage least squares) of the economic impact of land degradation on net farming income are given in table 13 below. The results show that out of twelve (12) independent variables, seven (7) are statistically significant. These are soil organic matter, education, plot on slope, erosion, property right, farm size, and farm size squares. Among these variables which statistically influence the net farming income, soil organic matter, education, property right, and farm size square have a positive coefficient, while the plot on slope, erosion, and farm size have a negative coefficient.

The endogenous variable used in the regression is “SOM”, and two (2) instruments are considered for him. The instruments are Temperature and Precipitation. They reflect the climate status.

Concerning the validation tests (under identification test, Sargan test, and endogeneity test), they are presented in table 14. It is to know if the instruments are relevant and valid and if the endogenous variable taken in the regression is endogenous.

Table 13: Instrumental Variables estimation results

NETLINCOME1	Coef.	Std. Err.	P>z
SOM	**0.070*** **	0.006	**0.000**
GENDER	0.002	0.011	0.847
AGE	0.000	0.000	0.61
EDUCATION	**0.016***	0.009	**0.063**
HHSIZE	0.001	0.001	0.561
PLOTSLOP	**-0.030***	0.016	**0.055**
EROSION	**-0.116*** **	0.011	**0.000**
ADVINF	-0.006	0.009	0.465
PESTICID	-0.005	0.009	0.615
PROPRIGHT	**0.107*** **	0.012	**0.000**
FSIZE	**-0.027*** **	0.004	**0.000**
FSIZESQ	**0.002*** **	0.000	**0.000**
_cons	0.810	0.034	0.000
Nb of obs = 780		Wald chi2(12) = 333.80	
Prob > chi2 = 0.0000		R-squared= 0.1180	

***, **, and * denotes significance at 1%, 5% and 10% respectively

Table 14: Validation tests

Under identification test	Anderson canon LR statistic: 279.105
	Chi sq(2); Pvalue: 0.0000
Over identification test	Sargan statistics: 0.1569
	Chi sq(1); Pvalue: 0.6919
Endogeneity test of endogenous regressor	Durbin Chi sq(1)= 35.8959; Pvalue=0.0000
	Wu-Hausman F(1; 766)= 40.4949; pvalue=0.0000

The under-identification test shows that the instruments are relevant because the p-value = 0.0000 is statistically significant and less than 1%, corroborating the rejection of H0, which is "the instruments are irrelevant". Similarly, the endogeneity test of the land degradation variable confirms that "SOM" variable is endogenous. The p-value obtained from the test is statistically significant at 1% (pvalue=0.0000).

For the over-identification test, the p-value (0.6919) of the Sargan statistic shows that the instruments are valid because it is greater than 10%. It allows us not to reject the null hypothesis.

As mentioned above, the results of Instrumental variables (two-stage least squares) show that seven (7) out of twelve (12) independent variables included in the model affect the net farming income in the study area (Table 13).

Apart from soil organic matter, education, property right and farm size squares which positively affect the net farming income respectively at 1%, 10%, 1%, and 1% level of confidence, plotslop, erosion and farm size negatively affect net farming income at 10%, 1%, and 1% respectively.. The positive sign of our interest variable "SOM" aligns with our hypothesis that stipulating the reduction of soil organic matter reduces the net farming income. According to table 13, it is statistically significant at 1% level of significance, and the positive sign of his coefficient means that if soil organic matter is reduced by 1%, the net farming income will be reduced by 0.07 unit on average, holding other factors constant. This finding is consistent with Mirzabaev et al. (2018), who found that farmers who experienced land degradation (reduction in soil organic matter) had 4.8 times lower net agricultural profit than those who had not experienced land degradation in Central Asia. Indeed, soil organic matter is the main pool of nutrient storage (Gerke, 2022), and its reduction by any means directly reduces land productivity which leads to income reduction. Many ways can be used to increase soil organic matter but the lack of knowledge and information allows farmers to focus on organic fertilizer that is not affordable to them and used in lower quantities. Farmers must be taught the various ways to increase organic matter in their fields through advice and information from agricultural experts. Also, the subvention of fertilizer by the government is required to allow farmers to use them efficiently because farmers have claimed that fertilizers are very expensive in the study area.

Education positively influences the net farming income at 10% level of significance, meaning that when the farmer is educated (for instance, having a college degree instead of a high school degree), his net farm income will also increase by 0.02 unit on average, keeping other variables constant. This result concurs with Jerop et al. (2018), Saguye (2017), and Serin et al. (2009), who found that education improves farmers' ability to collect, process, and apply knowledge from many sources to improve their production and net income. According to Serin et al. (2009), practical education in expert consulting and training services helps farmers increase their productivity, thus increasing their income and net income. In addition, educated farmers can interpret, obtain, and respond to information about sustainable land management and implement them to improve their net income (Jerop et al., 2018).

With climate change, agriculture nowadays requires enough information and advice about the use of inputs, sustainable land management practices, and the weather, so the government must establish and strengthen local agricultural institutions to promote SLM practices adoption, provide advice and information to farmers to help them deal with the issue of income reduction due to degraded land.

Plot on slope reduces the net farming income by 0.03 unit on average when it increases by 1%, taking all the other variables constant. The negative effect of plot slope on farmer income can be explained by the fact that plot on slope can facilitate erosion which is responsible for a decline in productivity. As the slope of the plots in the study area vary from gentle, moderate and very steep, the rate of humus decomposition becomes slow, reducing the land fertility (Fombe & Tossa, 2015). Also, the arable layer, fertile and rich in the organic matter of the land, is washed away elsewhere by water or wind because of the slope, leading to a reduction in land productivity that influences the net income. To reduce the negative effect of the plot on slope, policies must focus more on access to credit by farmers to easily implement new practices or technologies, such as anti-erosion protection mats. Also, farmers must be taught about the practices or techniques to be adopted when the field is on a slope. This task must be the responsibility of local agricultural institutions or other organizations working for sustainable land management.

Soil erosion reduces the net farming income by 0.12 unit on average, holding the other variables constant. It decreases soil fertility by erasing away the top layers of the topsoil, which constitutes the area the most fertile over time. Land fertility decreases by losing the topsoil, leading to poor productivity and net income. So when the productivity of the soil is low, it will impact the net income drawn from agriculture (Sulaeman & Westhoff, 2020). Also, soil that experienced erosion needs more investment to recover its initial state. This investment reduces the net farm income of the farmer.

Keeping other variables constant, property right increases the net farming income by 0.11 on average. The explanation for this positive effect between property rights and net farming income is the confidence that the owner of the land title has to invest in his land. This result is consistent with the results obtained by Kabubo-Mariara (2007), who found that farmers with more secure land rights are more likely to adopt SLM practices. Indeed, sustainable land management practices adoption is reputed to increase the net farming income because of the increase in soil productivity. An inverted U-shaped relationship is found between net farming income and farm size. It means that net farming income decreases when the farm size increases to achieve a threshold where any increase in farm size increases the net farming income. Das & Ganesh-Kumar (2017) found a similar result in their work titled "drivers of farmers' income: the role of farm size and diversification. The same result is obtained by Chand et al. (2011). Indeed, when the farm's size increases, the adoption of sustainable land management practices (fertilizer use, terrace, contour farming, improved seeds, irrigation, etc.) or technologies (soil erosion control, vegetation management, integrated soil fertility management, etc.) declines because it becomes more expensive to invest in these practices or technologies for farmers in developing countries. The greater use of these inputs in the small farm makes more intensive land use that would result in higher productivity. Of this fact, the result suggests that agricultural productivity in Ivory will increase if farmland is reduced, so the government must implement good land tenure policies that a necessary condition to increase investment in land and the efficient allocation of land and incentivize the use of inputs by subsidizing them to facilitate their acquisition to increase the net farming income.

3.5 Conclusion

This study relies on the production function and uses the instrumental variables (Two-Stage Least Squares) to evaluate the net farming income reduction due to land degradation in the Trays ecosystem. The results from the instrumental variables regression show that soil organic matter, education, and property rights positively influence the net farming income while the plot on slope and erosion reduce it. Also, an inverted U-shaped relationship is found between net farming income and farm size. Land degradation leads to more input use and lower crop yields. These inputs used are the consequence of a higher cost of production, which directly influences the net farmer income corroborating our hypothesis. To help the farmer increase their net farm income, government, non-government agencies, and community leaders must educate farmers on the necessity of shifting toward sustainable land management practices. In addition, subsiding the inputs (fertilizer, improved seeds), improving farm management skills, facilitating credit access, and making information available on sustainable land management practices could help farmers to increase their net income drawn from agriculture. Also, implementing a good land tenure policy will help farmers safely invest in some sustainable practices on their land.

This study, which focuses on the economic impact of land degradation on net farming incomes in the trays ecosystem in Ivory Coast, as with any study, also has some limits. It focuses on the soil's organic matter and considers one region. Future research must consider more regions to quantify the net income loss by farmers in the country.

4.0 CHAPTER FOUR: DETERMINANTS OF SIMULTANEOUS ADOPTION OF SUSTAINABLE LAND MANAGEMENT PRACTICES UNDER A CHANGING CLIMATE

4.1 Introduction

Land is one of the essential assets and a critical element on which the poor's livelihoods are based (TerrAfrica, 2009). Its degradation is a severe issue in improving the incomes, livelihoods, and food security of many people in developing countries, particularly in Sub-Saharan Africa. Land degradation reduces economic output and increases poverty for countries with their economy focused on agriculture, generally developing countries. It also intensifies rural conflict, negatively impacts biodiversity and exacerbates climate change (TerrAfrica, 2009).

Land degradation is due to direct and indirect drivers (Barger et al., 2018; IPBES, 2018a). Kirui (2016) distinguished two causes of land degradation, called proximate and underlying causes. Deforestation, one land degradation driver in the country, results from farmland expansion and energy needs, bushfires, road network development, and urbanization. Indeed, Ivory Coast is particularly vulnerable to land degradation because it is facing rapid population growth and high rates of hydric erosion and relies on mainly rain-fed agriculture vulnerable to climate change. Since its independence, the country has suffered from land degradation. In recent decades, this situation has worsened with a degradation rate of 11% of the territory, around 3.547.093 ha of soil from 2000 to 2010. The lands presenting a net productivity decrease are around 1.607.454 ha, and the carbon stock has decreased by 444.384 tons (MINSEDD, 2017).

With the growth of its population estimated at 29,389,150 million habitants (INS, 2021), it is necessary to improve the food system production in this developing country to achieve food security. To achieve this goal, sustainable land management adoption is an effective way to reverse the negative productivity trend of land in the country.

Sustainable land management is important for achieving sustainable development because it allows farmers and land users to benefit from their land. According to Liniger et al. (2011), sustainable land management increases land productivity by combining traditional and innovative methods. For TerrAfrica (2011), sustainable land management refers to a set of land-use practices that allow land users to maximize the economic and social benefits of the land as well as maintain or enhance its ecological functions. In addition, it makes the environment more resilient to threats and is guided by four principles. These are land-user-driven and participatory approaches; integrated use of natural resources at ecosystem and farming systems levels; multilevel and multi-stakeholder involvement; and targeted policy and institutional support, including developing incentive mechanisms for SLM adoption and income generation at the local level (FAO, 2008). However, although land degradation has increased considerably and the necessity to reverse its negative effect is needed, the adoption of sustainable land management remains low for the country drawing benefits from agriculture (MINADER, 2017).

The country is the first largest cocoa producer, accounting for 44% of total exportation. Agriculture represents 24% of the GDP formation, employs 70% of the active population (MINSEDD, 2017), and generates 66% of export revenues (MINADER, 2017). The government is committed to implementing land degradation neutrality to maintain its position as the first largest cocoa producer and continue to draw benefits from agriculture. Land degradation neutrality has led to elaborate National Plan to combat Land Degradation aligned with the ten-year framework (2008 – 2018) of the United Nations Convention to Combat Desertification (UNCCD).

To this must be added the ratification of laws and strategies in the fight against land degradation and its adhesion to the "Land Degradation Neutrality" program initiated by the UNCCD. All these commitments and adopted policies are susceptible to leading sustainable land management adoption in the country to improve the well-being of the farmers and increase the benefit drawn from agriculture.

This study about the simultaneous adoption of sustainable land management practices aims to analyze the effect of the simultaneous adoption of SLM practices under a changing climate on agriculture. Specifically, it is to identify the determinants of simultaneous adoption of sustainable land management practices under a changing climate in the trays ecosystem. The hypothesis on which this study is focused is that the decrease in rainfall determines the adoption of simultaneous SLM practices. The multivariate Probit model is used to achieve our study's objectives. The rest of the study is structured as follows: section two provides an overview of the best sustainable land management practices implemented in Africa. Section three presents an empirical literature review, section four deals with the material and methodology, section five discusses the study's findings, and section six concludes the study.

4.2 Overview of sustainable land management practice

One of the principles of sustainable land management is to increase land productivity (Liniger et al., 2011). It requires the reduction of high water loss through runoff and improves soil infiltration, livelihood, and ecosystems. Also, sustainable land management increases carbon sequestration from soil and agroforestry (Branca et al., 2013). For Branca et al. (2013), even though sustainable land management generally increases yields, the results vary by specific practice or technology and agro-climatic conditions. According to Liniger et al. (2011); Mirzabaev et al. (2015), many sustainable land management practices exist to reverse soil and land degradation. These are:

- Integrated Soil Fertility Management (ISFM)

ISFM is a set of soil fertility management practices combining different soil fertility amendment methods with soil and water conservation. It is defined by Vanlauwe et al. (2010) as a set of soil fertility management practices that include fertilizer use, organic inputs, and improved germplasm to maximize the agronomic efficiency use of the applied nutrients and improve crop productivity. ISFM aims to optimize crop productivity by integrating farmers' fertilizer, organic inputs, and germplasm use. It focuses on three main principles: maximizing organic fertilizer sources, minimizing nutrient loss, and using soundly inorganic fertilizer according to needs and economic availability.

ISFM can be practiced in dry savannas of the West African Sahel, moist savannas of Eastern, Southern Africa, and the tropics Roobroeck et al. (2016). Implementing this sustainable land management system helps to curb soil nutrient depletion and reduces deforestation Roobroeck et al. (2016). It is also required in areas with low and rapidly declining soil fertility (Liniger et al., 2011).

- Conservation Agriculture (CA)

Conservation agriculture is defined as minimal soil disturbance and permanent soil cover combined with rotations as a more sustainable cultivation system for the long run (Hobbs, 2007). It’s a farming system that prevents the loss of arable land while regenerating degraded land. It uses natural resources more efficiently through integrated soil management, water, and biological resources. It combines profitable agricultural production with environmental concerns and sustainability. It is supported by three fundamental principles: minimum soil disturbance, crop rotation, and permanent soil cover (Liniger et al., 2011). For Hobbs (2007), it's a holistic system with interactions between households, crops, and livestock through rotations and residues. The advantages of conservation agriculture are to improve soil fertility, decrease erosion, enhance crop growth and water infiltration, reduce labor, machinery use, and fuel costs, and increase biological activity (Ghaley et al., 2018). It also reduces reliance on mineral fertilizers and reduces Greenhouse gas emissions (Liniger et al., 2011). Conservation agriculture increases tolerance to temperature and rainfall change and can be applied in the agroecological zone and farming systems. It costs less in terms of money and time (Hobbs, 2007), and focuses on three principles that are: (1) Minimizing soil disturbance by reducing or zero-tillage, (2) Keeping the soil covered with organic materials of at least 30% soil cover, and (3) Using crop rotations/associations.

- Rainwater Harvesting (RWH)

RWH is the collection of rainwater to make it available for agricultural production or domestic purpose. It is the method by which precipitation that falls on a site is diverted, captured, and stored for future use (Medina, 2016). The goal of RWH is to minimize the effects of seasonal variations in water availability due to dry periods and to enhance the reliability of the production of agriculture. RWH encompasses three components: a collection area that produces runoff, a conveyance system through which the runoff is directed, and a storage system where water is accumulated or held for use. It applies to semi-arid areas with common seasonal droughts (Liniger et al., 2011; Medina, 2016) and highly degraded soils. RWH can also apply when ponded surface water contributes to insect or algae problems (Medina, 2016).

As advantage, this sustainable practice helps to reduce the risk of product failure due to water shortage in some regions with water stress, such as semi-arid or arid regions. Also, it helps to enhance the recharging of aquifers and permits crop growth in areas with water stress (Liniger et al., 2011). It provides water at or near the point where water is required or used. It can be operated and managed by the owner or by the public and can be reduced off-site damage.

- Irrigation Management (IM)

IM is defined as regulating water application to satisfy the water requirement of the crops without wastewater, plant nutrient, or energy.

Its goal is to achieve higher water use efficiency through more water collection and distribution.

The fundamental principle of IM is more crop per drop, which means water use efficiency. According to Liniger et al. (2011), Irrigation Management can be distinguished into two categories. These are traditional surface irrigation systems and micro-irrigation systems, including drip irrigation. These systems are commonly used to produce vegetables, fruits, and flowers. Irrigation management is most applicable in the region where water is scarce and can improve resilience to climate change. For Holzapfel et al. (2009), irrigation management involves determining the period of irrigation, the water quantity that the soil needs at each irrigation event, and during each stage of the plant. The particularity of this system is that it can improve the farmer's well-being through more production.

- Cross-slope barriers (CSB)

Cross-slope barriers are measures on sloping land in the form of earth or soil bunds, stone lines, and/or vegetative strips to reduce runoff velocity and soil erosion (Liniger et al., 2011). The purpose of cross-slope barriers is to reduce soil erosion by dividing the natural length of a hillside slope into shorter sections (Shaxson et al., 1990). They also permit ease of cultivation between the barriers, which are sited along contours. The cross-slope barriers can be used from soft to steep slopes in semi-arid, arid, sub-humid, and humid areas (Liniger et al., 2011). In semi-arid areas, they are used to conserve water, whereas, in the areas mentioned above, apart from the semi-arid, they are used to reduce soil erosion (Liniger et al., 2011).

Cross-slope barriers can, in a certain way, cope with extreme rainfall events. Their benefits are improving water management by storing water on the slope, increasing water infiltration by helping soil fertility, and increasing crop production.

- Agroforestry (AF)

Agroforestry is defined as the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits (USDA[14] , as cited in. Muschler, 2016). For Liniger et al. (2011), it is land-use systems and practices that associated trees and crops. Agroforestry includes traditional land-use practices: farming with trees, alley cropping, intercropping, multiple cropping, bush and tree fallow, etc.

It has a great potential to sequester carbon dioxide because of its perceived ability for greater capture and utilization of growth resources than the single-species crop or pasture systems. However, the amount of carbon dioxide sequestered by agroforestry will depend on the size of the agroforestry implemented, the great extent of environmental conditions, and the management of

[14] U.S. DEPARTMENT OF AGRICULTURE/ to know more: https://www.usda.gov/topics/forestry/agroforestry

the system (Nair, 2011). Also, agroforestry has the benefit of diversifying food and income sources, reducing land degradation, and improving its productivity through its ability to provide a good microclimate. It improves the structure of soil and organic carbon content. Similarly, it increases soil infiltration and improves the soil's biological activity and fertility (Liniger et al., 2011). In a nutshell, agroforestry could play a significant role in helping to maintain biodiversity and provide greater landscape connectivity (Montagnini et al., 2011, as cited in Nair, 2011).

- Integrated Crop-Livestock Management (ICLM)

Integrated crop-livestock management is the agricultural system that combines crop and livestock production in which the sub-product of one system becomes the input for another (Reddy, 2016). This system promotes organic agriculture. It transfers carbon dioxide and nutrients from one cropping season to the next (Ezeaku et al., 2015). Besides, for the farmers with limited land, it helps them to diversify their farm crop production and maintain a few livestock heads to exploit unutilized resources, enhance cash income, and improve the quality and quantity of food produced (Reddy, 2016).

ICLM is suitable for where livestock production is generally predominant in savannah regions. Also, it can be applied in many areas but needs to be adapted and modified to prevailing conditions (Liniger et al., 2011). Following Rota (2009), as cited in Reddy (2016), three types of integrated crop-livestock management are distinguished, focusing on the technique agriculture use, the degree of integration among crop and livestock, and the local agro-ecological conditions. These are pasture cropping system, nonchemical input cropping system, and holistic management system.

- Pastoralism and rangeland management (PRM)

PRM is defined as the extensive production of livestock using pastures and browse. It is focused on open grazing lands (TerrAfrica, 2011). Pastoralism and rangeland management are found in semi-arid and arid areas. Pastoralism is a production system in which domestic livestock and humans live together. It contributes to dryland ecosystems' health (Nassef et al., 2009). Indeed, grazing management can contribute to biodiversity and promotes biomass production. Also, with mobile pastoralism, dryland ecosystem health is improved.

Another thing is that pastoralism efficiently uses extensive rangelands and could cope with the variability of the climate. Scanes (2018), distinguished four types of pastoralism management. These are nomadism, defined as exclusive pastoralism migrating irregularly to new pastures for grazing; transhumance, which is exclusive pastoralism with regular back and-forth migrations; agro-pastoralism, which includes both livestock and crops; and enclosed pastoralism.

- Sustainable planted forest management (SPFM)

Forest plantation, according to FAO (2006) as cited in Masiero et al. (2015), is a forest where native and introduced species are established through seeding or planting for protection or productivity. It is the forest established through planting or seeding that, at stand maturity, resembles or will resemble a naturally regenerating forest (Ivetić, 2019). The main goal of planted forests can be environmental protection, rehabilitation of degraded areas; or commercial (Liniger et al., 2011). It helps to relieve pressures on natural forests and reduces the harvest by about 20% in Africa. It also supports ecosystem service maintenance from natural areas and contributes to carbon sequestration (Masiero et al., 2015). Planted forests' applicability and sustainability depend on how they are managed and what they replace. They must complement the existing forest to reinforce the environmental and production services. Also, planted forests with fast-growing species should be established in areas with no water constraints (Liniger et al., 2011). Proper sustainable planted forest management must be established to avoid wood shortages and deforestation of natural forests.

As the main benefit, sustainable planted forest management helps to increase the availability of wood products and fuelwood, rehabilitates degraded areas such as eroded or overgrazed areas, to reduce the pressure on natural forest, and capture carbon dioxide (*Ibid.*).

- Sustainable Forest Management (SFM)

SFM is defined as the ways and processes of managing forest resources to meet society's varied needs, today and tomorrow, without compromising the ecological capacity and the renewal potential of the forest resource base (S. Wang, 2004). It is the best available practice, based on current scientific and traditional knowledge, which allows multiple objectives and needs to be met without degrading the forest resource (Higman et al., 2005, as cited in Hansen et al., 2010). It ensures that the goods and services derived from the forest meet the need of the present day while securing at the same time their continued availability and contribution to the development of the long term (Liniger et al., 2011). Also, it plays an important role in biodiversity conservation and provides ecosystem goods and services such as control of desertification, water quality conservation, and improvement. SFM can be applied to any primary or secondary forest, particularly in drylands. With the growth of the population, pressure on forests has increased, so the effort will be made to create protected forest areas or protect remaining forest areas. Thus, national and local authorities must be strengthened to assess, maintain and protect the remaining forest resources.

- Sustainable Rainforest Management (SRFM)

Sustainable rainforest management is the fact that the goods and services derived from natural forests meet the needs of the present day and secure their continued availability and contribution to long-term development. SRFM is applied to any type of natural primary or secondary rainforests, mainly in tropical and mountain areas. It can be managed in some ways to reduce deforestation and land degradation. These ways are education that consists of promoting the value and benefits associated with rainforests and increasing public awareness of the importance of rainforests; logging and replanting, which permits forest reconversion; ecotourism which encourages sustainable tourism and creates jobs for local people. The money generated must be used to protect and conserve the rainforest for future generations (BBC Bitesize, n.d.)[15]. The main benefits of SRFM are to improve the livelihoods and the welfare of the population, improve the availability of water, maintain the ecosystem, provide critical buffer against climate change and contribute to the global carbon balance (Liniger et al., 2011). To achieve sustainable rainforest management, good forest governance and land use planning are the prerequisites. These sustainable land management practices are the best (Liniger et al., 2011).

4.3 Literature review

This section reviews the adoption of SLM practices, factors influencing SLM adoption, the link between climate change and SLM, the theoretical framework, and the empirical literature on the factors influencing the simultaneous adoption of sustainable land management practices.

4.3.1 Sustainable land management practices adoption in Africa

SLM is the best way to cope with or reverse land degradation (Cordingley et al., 2015). Among all regions in the world, Africa, particularly sub-Saharan Africa, is the one that has the highest rate of land degradation. Around 7 percent of his degraded land is classified into those which are so severely degraded (FAO, 1999; as cited in Wachira, 2013). Despite the efforts to promote SLM to farmers, the adoption of SLM remains low. With the high poverty rate in the region, many farmers

[15] https://www.bbc.co.uk/bitesize/guides/zwy7sg8/revision/5

adopt conventional practices. Sometimes, wealthy farmers with better market access adopt SLM practices (Tripp, 2006; as cited in Cordingley et al., 2015). Indeed, during the 1980s, 15 million hectares of forests were cleared in Africa yearly.

Slightly reduced to 12 million yearly in the 1990s, the deforestation rate estimated at around 0.6% per year is among the highest in the world. Africa is the second region facing soil erosion (Borrelli et al., 2017). Its average rate for soil erosion in 2001 was around 3.51 Mg $ha^{-1}yr^{-1}$ showing the non-adoption or the low adoption of SLM practice. Fertilizer use, one SLM practice that maintains soil fertility remains underuse in Africa. Indeed, the fertilizer application rate in the fields is low in comparison to other parts of the world. The average fertilizer use in Africa was estimated at 8kg/hectare. Combining all crops, the farmers of Africa apply 17kg/ hectare compared to the other region, with 135kg/hectare[16] of arable land as the average fertilizer application (African Development Bank, 2020). In percentage, Africa's fertilizer use is 3% compared to other regions.

Conversely to the practices mentioned above, some practices such as fallow, intercropping, and crop rotation have been implemented. With the population growth and the increase in degraded land, the fallow period has been reduced, accentuating land use frequency. Intercropping, an ISFM practice, is adopted by smallholders in Africa, particularly Sub-Saharan Africa (Matusso et al., 2014). This SLM practice adoption minimizes the risk of total crop failures, gets more food for livelihood and increases income (ibid).

Concerning crop rotation, it has been classified as the most adopted practice (Alhameid et al., 2017). Its adoption is cheaper and allows it to reconstitute soil fertility, control weeds, diseases, and insects, and preserve the environment (Alhameid et al., 2017; Chiputwa et al., 2011). For Alhameid et al. (2017), intercropping of legumes and cereals, crop rotation, and the sole cropping system are the most SLM practices adopted by African farmers.

4.3.2 Factors influencing the adoption of SLM practices

Factors influencing the adoption of SLM practices can be classified into two groups: positive and negative factors. Those that positively influence the adoption of SLM practices are called

[16] For more informations see https://gro-intelligence.com/insights/articles/fertilizers-in-sub-saharan-africa

incentivized factors, while those that negatively influence the adoption of SLM practices are called barriers.

4.3.2.1 Factors incentivized SLM practices adoption

SLM includes three (3) dimensions: ecological, socio-cultural, and economic (Hurni, 1997, as cited in Liniger et al. 2011). These dimensions are interconnected. Ecologically, SLM practices fight against land degradation. Socially, it maintains, protects, and increases the productivity of soil that is directly linked to food security and well-being, and economically, it pays back investments made by farmers. However, many African farmers or land users do not adopt its implementation because some factors influence it. What are the factors that incentivized the adoption of SLM practices? Factors incentivizing SLM practices can be classified into demography and socioeconomic factors, farm characteristics, biophysical factors, and institutional factors. Several studies pointed out these factors as incentivizing the adoption of SLM practices (Etsay et al., 2019; O. Kirui, 2017; Oduniyi & Tekana, 2021; Saguye, 2017; Toma et al., 2017). As examples of demography and socioeconomic factors playing a significant role in adopting SLM practices, Etsay et al. (2019) quoted age, gender, level of education, household size, income, and labor availability.

For farm characteristics, these are farm size, plot size, slope, irrigation access, etc. The factors playing an important role in the institutional aspect are support programs, access to credit, extension services, market access, etc. At these factors, Feder et al. (1985); Olwande *et al*. (2009); Boyd and Turton (2000) as cited in Saguye, (2017), added access to advice and information about agriculture, input accessibility, risk aversion, experience in farming, technology awareness, technical and economic feasibility of technology use, farm tools adequacy, soil fertility, and favorable policies implementation as variables of factors influencing the adoption of SLM practices. On their side, Van Song et al. (2020) insist that farming experience, risk preference, total annual crop size, SLM practices knowledge, perennial crop size, and total forest influence the decision to adopt SLM practices.

4.3.2.2 Barriers to SLM practices adoption

Barriers to SLM practices adoption are factors affecting the adoption of SLM practices. The barriers identified to adopting SLM practices are linked to the institutional and governance, technological, ecological, economic, and socio-cultural aspects (Sanz et al., 2017). Institutional and governance problems jeopardize the adoption of SLM practices. Indeed, some political institution inhibiting decision-making on land tenure issues and not encouraging cross-sectorial can create conflict over time within a population. For the technological aspects, lack of appropriate technologies access, practices, or equipment are reputed to be a major barrier to SLM practices adoption. It is explained by inadequate information and knowledge concerning SLM practices or by insufficient resources in labor, land, input, water, etc.

Regarding the ecological aspect, it concerns implementing some SLM practices that can succeed or fail at certain periods and with environmental factors. Also, SLM practices well implemented in one location may not be suitable for another because the locations may have different biophysical and socioeconomic contexts. Concerning economic and socio-cultural aspects, finance restriction and capital unavailability negatively affect the adoption of SLM practices. These two variables are the primary motivations by land users to select SLM practices (Sanz et al., 2017). For Adimassu et al. (2012); Teklewold et al. (2013), poverty, insecure land tenure, volatile market price for agricultural products and inputs, limited extension services and infrastructure, and lack of financial access and labor are the social factors considered as barriers that influence the adoption of SLM practices negatively. Adimassu et al. (2016) have identified a set of characteristics that limited the implementation of SLM practices. These are farmers' capabilities to invest in SLM practices, farmers' incentives to adopt SLM practices, and the insufficient enabling conditions that motivate farmers to SLM practices adoption.

4.3.3 Climate change and SLM

Climate change plays an important role in land degradation through high temperatures, increased rainfall intensity, flooding, sea-level rise, and drought (IPCC, 2020b; Webb et al., 2017b). Its negative effect on land use, food security, and agriculture is predicted to impact Africa, particularly sub-Saharan Africa (IPCC, 2018). It contributes to land degradation by making current land management practices unsustainable through more land conversion (Wachira, 2013) and leads to biodiversity loss. Conversely, land degradation contributes to climate change by releasing greenhouse gas into the atmosphere. Also, land degradation caused by reductions in vegetation cover and unsustainable land management influences the local microclimate by decreasing air humidity and increasing soil temperature. In this context, SLM practice is crucial to reverse the negative trend of land productivity, ensure food self-sufficiency and food security, improve farmers' wellbeing, and protect biodiversity everywhere. It can also reduce vulnerability to climate change, help farmers or land users to adapt and mitigate climate change through carbon sequestration and greenhouse gas emissions (Pender, 2009). According to Sanz et al. (2017), most SLM practices improve soil fertility and mitigate climate change by removing carbon dioxide in the atmosphere. Their large-scale adoption in all managed ecosystems could sequester around 2 Gigatons of carbon annually (Sanz et al., 2017).

4.3.4 Theoretical framework of sustainable land management adoption

The Theoretical framework of SLM adoption is essentially based on the property rights approach, risk preferences, and cost-benefit analysis.

4.3.4.1 Property rights approach

Property rights are important in agriculture. It can incentivizes or disincentives the adoption of SLM practices (O. Kirui & Mirzabaev, 2015; Sanz et al., 2017). For the property rights theorists, if land rights are clearly defined, fully, and exclusively assigned, land users would be incentivized to invest and adopt some SLM practices in their land to take care of their land, resources and use them in a socially optimal way (Heltberg, 2002; Wachter, 1992a). The fact that land rights are often imprecise, unspecified, contested, or non-existent is widely seen as a problem for developing countries. It pushes land users to not often invest in their assets to take care of them because they may escape to them at any time. Also, insecure or short-term property rights can constraint the adoption of SLM practices, the natural resources management and discourage stakeholders who act as stewards of land and natural resources (Aggarwal & Elbow, 2006). According to Heltberg (2002), land rights and their enforcement give the security of tenure and hence the incentive to undertake investment in land.

4.3.4.2 Risk preferences

Risk preference is the attitude of people who take risks (Dadzie & Acquah, 2012; Khanal et al., 2019). Farmers' decision to take risks depends on the degree to which they accept risk. Indeed, some farmers or land users are willing to take risks compared to others. According to Van Song et al. (2020), the attitudes of farmers who take risks are related to their financial ability to accept a small gain or loss. according to Wang et al. (2016), farmers or land users with a higher risk preference are more likely to adopt SLM practices.

4.3.4.3 Cost-benefit analysis (CBA)

Cost-Benefit analysis assesses the financial viability of investments. It measures the economic changes due to changes in the use of resources (Yrjölä & Kola, 2008). It helps to determine if the benefits exceed costs and which alternative produces the highest benefit of investment. Its goal is to maximize the difference between the benefits and costs. The net benefit, which is the difference between the benefits and cost, indicates the efficiency of the measures applied (Yrjölä & Kola, 2008). In agriculture, cost-benefit analysis can compare the relative financial effectiveness of other SLM adoption practices. For Kansanga et al. (2021), farmers' adoption of SLM practices is shaped by incentives emanating from cost-benefit analysis. Therefore, the decision of farmers to adopt SLM practices must be made in the context of the financial and non-financial benefits that will accumulate in the short and long run (Mcharo & Maghenda, 2021).

4.3.5 Empirical literature review

Although land degradation continues to increase in developing countries, particularly in sub-Saharan Africa, the adoption of SLM practices is shallow. Several studies indicated that adopting sustainable land management was affected by either socioeconomic factors of household characteristics, institutional factors, and biological factors of farmer plots (Adimassu et al., 2016).

For Kirui (2017), the factors determining the adoption of sustainable land management practices include farmer and plot characteristics, attitudinal factors about land degradation, institutional factors, technology attributes, and profitability. However, some factors favoring sustainable land management adoption encompass level of education, input and output markets access, credit availability, property rights, workforce and physical capital, and management practice benefit. His study has analyzed the determinants of sustainable land management practices in Ethiopia, Malawi, and Tanzania. He found that extension services, title deeds and distance to the market incentivize SLM adoption. He used three approaches to identify the determinants of SLM adoption: logit regression, Poisson regression model, and multivariate Probit model and found that biophysical factors, including rainfall, temperature, agroecological characteristics, and elevation, are factors influencing sustainable land management practice adoption. For demographic and socioeconomic factors, household head education level, farm size, age, family size, access to credit, land tenure, membership, savings, proximity to markets influence decision to adopt SLM practices.

Adimassu et al. (2016), in their review and synthesis concerning the determinant of farmers' investments in sustainable land management practices in Ethiopia, classified the factors influencing farmers' decision to practice sustainable land management into three groups. These are incentives, capacity, and external factors. For the authors, capacity factors take into account financial capital, workforce, land tenure, and knowledge, while incentive factors emanate from cost-benefit considerations. They consider institutional support, extension services, land policy, and credit access as external factors. Their study identified some determinants that affect farmers' SLM adoption practices. The study found that farmer capacity and incentives to invest in SLM practices are limited, and conditions for motivating farmers are insufficient. As household-level determinants, the study showed that the experience and age of a farmer influence the decision to implement SLM practices. These determinants can be either favorable or unfavorable. Older and younger farmers are expected to positively impact SLM practices because the first has longer farm experience, and the second has a long planning horizon.

Similarly, literacy positively or negatively affects farmers' SLM practices adoption. The positive effect is that literate farmers can acquire and use information easily to adopt SLM practices. The negative effect is that farmers with higher education can calculate the costs and benefits of adopting SLM practices, and they will invest if they think it is more profitable.

Kansanga et al. (2021) used cross-sectional data with logistic regression in their study carried in in Malawi. They have examined the concurrent adoption of sustainable land management practices in the short and long run. They have found that farm size, active labor, extension service, wealth and women's autonomy, and people with chronic illnesses in the household determine the adoption of sustainable land management practices. For the authors, when farm size increases by one unit, the odds of adopting simultaneous SLM practices in the short and long-run increase by 45%. The authors have shown that farmers in richer categories were likelier to implement sustainable land management practices in the short and long term. Concerning households without chronically ill people, they were more inclined to adopt both short and long-term sustainable land management practices simultaneously. Also, they found that farmers exchanging information about farming systems with other farmers have a great chance to adopt sustainable land management practices than their counterparts.

Issahaku & Abdulai (2020), with data collected in five districts, examined the effect of SLM practices adoption among smallholders in Ghana. The findings of their study showed that farmers adopting SLM technology are more efficient than those using conventional technologies. The same result was obtained when the authors used the metafrontier estimates. Also, the results showed that sustainable land management adopters are 7.5 times more efficient than their counterparts. Through the results obtained from the Probit model with the stochastic production frontier equation, the authors pointed out that ownership of machinery and extension services have positive implications for adopting SLM technology. The data envelopment analysis efficiency scores showed that the adopters of SLM technology obtained generally higher efficiency scores than the nonadopters. The percentage of farmers adopting SLM technology is 42% compared with the nonadopters, which is estimated at 36%. Another finding of the authors was SLM adopters and non-adopters used excess herbicide at an average of 57% and 26%, respectively. Seeing that the excessive use of herbicide damages the environment, the authors have discussed the efficiency scores of the data envelopment analysis. The clog log specification results show that adoption status, access to credit, extension access, and household size influenced technical efficiency scores. Also, SLM adoption, access to credit, and tenure security influence environmental inefficiency.

In the study dealing with the Determinants of Sustainable Land Management (SLM) Practices adoption in Ethiopia, using logistic regression, Saguye (2017) argued that nine (9) factors played a determinant role in the adoption of SLM practices. These factors are household head age, total livestock owned, membership, land degradation perception, household education level, plot slope, title deed, and farmer perception about introducing land management practices efficacity. For the author, household head characteristics like age affect positively or negatively the SLM practices implementation. Older farmers are less inclined to SLM practices investment because of their short planning horizons than younger farmers with long planning horizons. Concerning off-farm activities, they reduced the availability of adopting sustainable land management practices. According to the author, farmers having external activities may not have sufficient time to invest in their fields. The author pointed out that the total livestock owned and extension contacts favor the SLM practices adoption. The first one is significant at 5%, and the author's argument is focused on the fact that animal manure is one component of compost/manure production. The second one is significant at 10%. The author explains it by the fact that messages gained by farmers from other farmers or people in charge of teaching some SLM practices help them introduce some land management practices to take care of their land and improve their fertility.

Regarding farmer perception about introducing land management practices efficacity and perception of land degradation severity, these variables positively influence the adoption of SLM practices and are respectively significant at 5% and 1% levels of confidence. The educational level of sampled household heads, land tenure, and plot on slope positively influence the adoption of sustainable land management practices, respectively, at 5%, 5%, and 1%. Indeed, the author argued that longer schooling increases the ability of literate farmers to access information and strengthen their analytical capabilities with new practices or technologies. In terms of land tenure, the author argued that a lack of land title deeds discourages people from investing in new land practices. Similarly, for the slope of the farm plots, the author argued that farmers are disposed to take care of land which higher slopes.

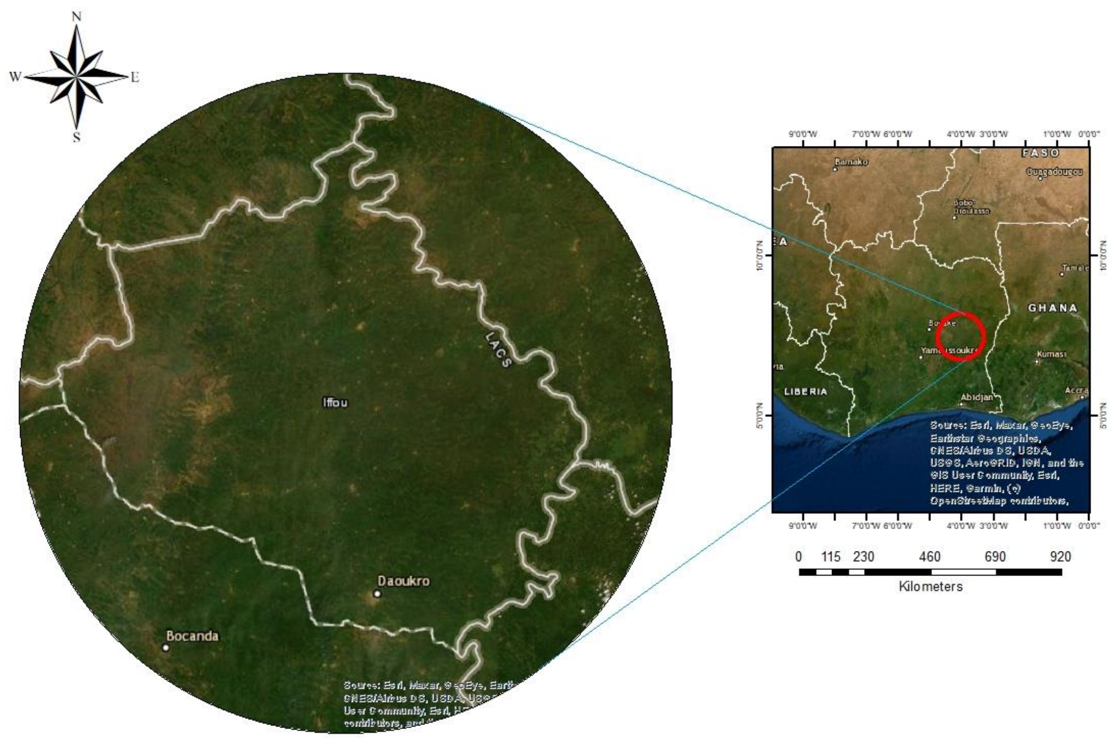
Seeing that the studies conducted on the simultaneous adoption of SLM practices didn’t include the aspect of climate change, we think that it is important in this study to focus on it. So this study fills the gap in the literature by including farmers' perceptions of climate change in their decision to adopt sustainable land management practices. It is to know whether a change in temperature and precipitation plays an important role in adopting the SLM practices.

4.4 Methodology

4.4.1 Study area

The study was conducted in Ivory Coast, a West African country located between 4°30' and 10°30 of latitude North and 2°30' and 8°30' of longitude West with an area of 322,462 km^2 (A. M. Kouassi et al., 2022). The trays ecosystem is located in the country's central-eastern and northern parts. For our study area in this ecosystem, we have considered the “Iffou region,” located in the central-eastern part (figure 10). The choice of this region is because it is facing land degradation for two decades. It was the cocoa basin after the independence and now experienced depopulation because of the reduction of their agricultural productivity. The new cocoa basin is located in the Southwestern part of the country. The Iffou region covers an area of 8955.05 km^2, and its population is estimated at 378,560 inhabitants (INS, 2021). The climate in this region is of the equatorial transition regime type (A. M. Kouassi et al., 2022). It is hot and humid and alternates four seasons divided into two rainy and two dry seasons (KOUAKOU et al., 2017). The great rainy season extends from March to mid-July to cope with the small dry season, which lasts from September to October. As for the great dry season, it lasts five months, starts in November and intersperses with an unstable period of harmattan. The region possesses two types of vegetation: grassy savannah in the west and degraded forest in the east, north, and south. It is crossed by two principal rivers, “Comoe” and “N’zi,” which are permanent regimes, and the others are seasonal. We can quote “Ifou,” the region's name among them.

Figure 10: Study area



Realization: 2022 Source: author using ArcGIS

4.4.2 Data source and sampling procedure

The data used in this study were gathered from farmers in the "Iffou region" via a questionnaire. A two-stage survey was carried out. The questionnaire was tested in the first stage in a few villages in the study area. Before conducting the second stage, information gathered from the first stage helped us to improve the quality of the questionnaire. The second stage officially gathered the necessary information to carry out the study.

Individual interviews collected information about sociodemographic characteristics, economic activity, field number, production system, crop yield, SLM practices awareness, farm management, and adoption of SLM practices. The sample size was determined using the Cochran equation that is:

$n_0 = \frac{Z^2 PQ}{e^2}$ Where n_o denotes the sample size, z the z-score equal to 1.96, taking into account a confidence level estimated at 95%, P is the proportion of the population set at 0.5, Q is equal to 1-P, and the desired margin error equal to 0.05 is e (Agresti & Finlay, 2009). The minimum sample size is estimated at 384. However, to increase the quality of the study, 785 farmers were invited for interviews in the trays ecosystem (Table15). A multi-stage sampling method has been employed to obtain the data. Firstly, we purposively selected the “Iffou region” because it is severely affected by land degradation. Secondly, eight villages were randomly selected in the region. Thirdly, we used a simple random technique to select the farmers' respondents. The data (cross sectional data) obtained include some socioeconomic (education, age, household size, income, gender), climate data (temperature and precipitation), and institutional characteristics data (membership, credit access, and advice and information).

Table15: Sample size in the Trays ecosystem

Ecosystem	Region	Name of village	Farmer sampled	Total population	Total farmer sampled
Trays	Iffou	Adikro	82	777	785
		Akanangbo	85	508	
		Donguikro	101	850	
		Koffi Amonkro	130	2500	
		Nafana	113	1598	
		Tetesi	97	1056	
		Ahouan	85	843	
		Koffi-Akakro	92	1447	

Source: Author compilation

4.4.3 Model specification

Farmers adopt some practices or a set of practices for SLM based on the benefits associated with it to deal with land degradation. Simultaneous adoption of SLM practices refers to using at least two SLM practices in the same plot. The different SLM practices identified in the study area include fertilizer use, crop rotation, intercropping, fallow, mulching, and improved seed use. These types of practices are often implemented concurrently or sequentially because they are complements, substitutes, or supplements. Therefore the decision on SLM practices adoption is multivariate (O. Kirui & Mirzabaev, 2015; Teklewold et al., 2013). Focusing on one single-practice adoption will lose valuable details on the interdependent and concurrent sustainable land management adoption and also will neglect that farmers are sometimes confronted with various choice options of practices (O. K. Kirui & Mirzabaev, 2015). As a result, a binary logit or probit model does not capture the relationship or dependency of SLM methods (Oduniyi & Tekana, 2021). To identify the determinants of simultaneous adoption of SLM practices, the Multivariate Probit model is used. It is used because it simultaneously models the influence of explanatory factors on each of the six practices, allowing potential correlations of unobserved factors among the adoption decisions. It takes also into account the correlation of the error components of adoption equations and aids in understanding the interrelation of unobserved disruptions of various SLM activities. Similarly, the Multivariate Probit regression uses a binary probit model to simultaneously describe the effect of explanatory factors on each distinct practice. It overcomes issues or flaws related coming from the univariate probit model (Dougherty, 2011), and binary dependent variables (Y_{ipj}) distinguish it. It is presented by equation (1):

$$Y^*_{ipj} = X_{ij}\,\beta_j + \varepsilon_{ij} \qquad j = 1, \ldots, 6 \quad \text{and} \qquad (1)$$

j denotes the practice of SLM available, namely fertilizer use, crop rotation, intercropping, fallow, mulching, and improved seed use.

The latent choices in equation (1) are translated into the observed binary result equation for each option using the indicator function. The indicator function is presented as follows:

$$Y_{ij} = \begin{cases} 1, & if\ Y*ij > 0 \\ 0, & otherwise \end{cases} \qquad (2)$$

Equation 1 assumes that the ith farmer has a latent variable Y*ipj that represents the unobserved preferences linked with the jth SLM practice decision. Y^*_{ipj} is assumed in linear combination with the explanatory variables X_{ipj} that affect the adoption of jth SLM practice and nobserved characteristics captured by the stochastic error term ε_{ipj}.

Y^*_{ipj} indicates if a farmer has adopted or not a specific SLM practice on his field. The reduced form of the model applied to our study is:

$$A_{ij} = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \qquad (3)$$

Where; $\boldsymbol{A}_{ij}$ =Adoption of SLM practice *j* in the plot i; X_i a set of factors including demographic factors, institutional factors, physical factors, economic factors, and attitudinal factors; β_i the slopes parameters of the model, and ε_i the disturbance terms. Table 14 summarized the independent variables and a brief description alongside the direction of the hypothesized effects of these variables on SLM adoption are given below.

In equation (1), the Error terms jointly follow a multivariate normal distribution with zero conditional mean and variance normalized to one, where $\varepsilon_{ipj} \sim MVN(0, \Omega)$ (Jerop et al., 2018; O. Kirui & Mirzabaev, 2015; Teklewold et al., 2013). The symmetric covariance matrix Ω is given by:

$$\begin{pmatrix} \varepsilon 1i \\ \varepsilon 2i \\ \varepsilon 3i \\ \varepsilon 4i \\ \varepsilon 5i \\ \varepsilon 6i \end{pmatrix} \sim \begin{pmatrix} 1 & \rho 12 & \rho 13 & \rho 14 & \rho 15 & \rho 16 \\ \rho 21 & 1 & \rho 23 & \rho 24 & \rho 25 & \rho 26 \\ \rho 31 & \rho 32 & 1 & \rho 34 & \rho 35 & \rho 36 \\ \rho 41 & \rho 42 & \rho 43 & 1 & \rho 45 & \rho 46 \\ \rho 51 & \rho 52 & \rho 53 & \rho 54 & 1 & \rho 56 \\ \rho 61 & \rho 62 & \rho 63 & \rho 64 & \rho 65 & 1 \end{pmatrix} \qquad (4)$$

The off-diagonal elements in the covariance matrix that are of particular interest represent the unobserved correlation between the stochastic components of the different SLM practices.

- Independent variables

The relevant demographic factors included are age, household size, gender, education, and farmer experience. Younger farmers are more likely to easily adopt sustainable land management because they have a long horizon of planning than the elderly (Guo et al., 2015; Saguye, 2017). Also, Younger farmers are often better educated and more aware of the benefits of innovations (Jerop et al., 2018). Gender of farmers has a significant impact on sustainable land management practices. We hypothesized that male farmers are more likely to invest in sustainable land management. Aminu et al. (2018); Kolapo et al. (2022); Oduniyi & Tekana (2021) pointed out the positive relationship between male farmer and the adoption of SLM practices. Gebreselassie et al. (2013)

contend that cultural and social setups can restrict women's access to land and external inputs making the adoption of SLM practices more difficult. Women have limited land access, labour and seed input (Mishra et al., 2017). SLM practices are positively influenced by household size.

It has been established by authors like Belay & Bewket (2013) that larger households have higher labor endowments and adopt SLM more frequently. Education is assumed to have positive impact on the farmer decision to adopt SLM practices (Aminu et al., 2018; O. K. Kirui & Mirzabaev, 2015; Saguye, 2017). For Saguye (2017) farmer having a longer schooling may increase their ability to access information about SLM adoption and implement them easily. Farmer experience is assumed to have a positive influence on the SLM practices adoption indicating that farming experience increases the likelihood of adopting SLM practices. Kolapo et al. (2022); Oduniyi & Tekana, (2021) have ascertained this positive relationship.

Relevant institutional factors identified from the literature which influence the adoption of SLM practices are extension contact (membership, advice and information) and access to credit. Extension contacts play an important role in farmer decision to adopt SLM practices. Extension contacts, according some authors, impact positively the adoption of SLM practices by farmers. Extension contacts help farmer to gain message, information about SLM from other farmer and development agent. The information gained by farmers accelerate their attitude towards SLM practice adoption (Jerop et al., 2018; Kolapo et al., 2022; Saguye, 2017; Toma et al., 2017). Access credit, in the process of implementing the SLM practices, is assumed to have a positive effect. Access to credit makes SLM adoption more likely (Jerop et al., 2018; Kolapo et al., 2022; Saguye, 2017). Babalola & Olayemi (2014); Miheretu & Yimer (2017); Teklewold et al. (2013); Toma et al. (2017) have established the positive effect of access to credit end SLM implementation.

The physical factors used in this thesis include farm size, total farm, land fertility (quality of land), and plot on slope. The variables like farm size, total farm and the plot on slope are hypothesized to have positive influence on the SLM adoption. Van Song et al. (2020) found positive relation between farm size and the adoption of SLM. For Saguye (2017), the positive relationship is between plot on slope and the SLM practice adoption.

The economic factors in this thesis are Income and off-farm employment. Farmer income is supposed to have a positive impact in the decision of adoption SLM practices. Previous literature show a positive influence of income on SLM practices adoption (Dung, 2022; Toma et al., 2017). The effect of off-farm employment are not clear established. The authors like Jerop et al. (2018) associated the positive relationship between off-farm and SLM adoption decision. Conversely, Saguye, (2017) found negation relationship. According to him, farmers who have off-farm employment may encounter time for investing in their farm.

The attitudinal factors concern the perception of farmers about rainfall and temperature. They have supposed to influence the farmer's decision to adopt SLM practices. According to farmers surveyed, their perception help them to take decision to adopt or not SLM practices.

Table 16: Definition of all variables used in the MVP model

Variables	Description
Dependent variables(Adoption of SLM practice)	
Fertuse	Fertilizer use, 1 if the farmer uses fertilizer, 0 otherwise
Fallow	Fallow, 1 if the farmer practices fallow, 0 otherwise
Mulch	Mulching, 1 if the farmer practices mulching, 0 otherwise
Croprot	Crop rotation, 1 if the farmer practices crop rotation, 0 otherwise
Intercrop	Intercropping, 1 if the farmer practices intercropping, 0 otherwise
Impseed	Improved seed, 1 if the farmer uses improved seed
Independent variables	
Demographic factors	
Age	Age of respondent in year
Hhsize	Number of people in the household
Gender	Gender of the respondent; 1 male, 0 otherwise
Education	Literacy of the respondent; 1 if the respondent is literate, 0 otherwise
Farmexp	Farmer experience in year; 1 if the farmer practice agriculture less than 1 year, 2 between 1 to 5, 3 between 6 to 10, and 4 more than 10 years
Institutional Factors	
Membship	Membership in local association; 1 if the farmer belongs to an association, 0 otherwise
Credac	Credit access; 1 if the farmer has access to credit, 0 otherwise
Advinf	Advice and information about SLM; 1 if the farmer receives advice and information about SLM practices/technologies, 0 otherwise
Physical factors	
Fsize	The size of the main farm in hectares
Totfarm	Total farm
Landfer	Land fertility, 1 if land is fertile, 0 otherwise
Slope	Slope of the plot; 1 if steep and 0 otherwise
Economic factors	
Income	Estimated average income earned annually in CFA
Ofarmem	Off-farm employment, 1 if a farmer has off-farm employment and 0 otherwise
Attitudinal factors	
Rainfdec	Rainfall decreases, 1 if the farmer perceived the decrease in rainfall, 0 otherwise
Tempinc	Temperature increase, 1 if the farmer perceived the increase in temperature, 0 otherwise

4.5 Results and discussion

The data for this study came from farmer surveys carried out in the trays' ecosystem.

4.5.1 Descriptive statistics of variables

This section discusses the descriptive analysis findings. Table 17 (see appendix A) displays the mean and standard deviation of all variables used in the regression models.

Demographic factors

Of the farmers interviewed, about 66% were men, while the remaining 34% were women in the ecosystem. This result observed in the study areas reveals that men were more implicated in agriculture than women. The average farmer's age was 47 years, and 48% of these farmers were educated (at least six years of formal education). The farmers interviewed have, on average, eight people in charge, which shows that the ecosystem is densely populated. The result indicated that the farmers interviewed had more than ten (10) years of experience in agricultural practice because table 17 shows 3.6 as the mean of farmer experience.

Institutional factors

Membership in local associations was estimated at 8% in the trays ecosystem. This percentage showed that the culture of belonging in an association or group was still very low in the study area. It is the same for credit access. The percentage of the farmers who stated they have got credit was 9.6% during the last ten years. This is a low percentage for a country where agriculture accounts for 23% to GDP formation.

Physical factors

According to the results, 2.3 hectares is the farm size exploited by farmers, highlighting that many authors qualify farmers in Sub-Saharan Africa as small farmers. The total farm available to farmers in the study areas is estimated at 3, and plots on slope accounted for around 27.5%. For land fertility, according to farmers interviewed in the study area, 42% have stated that their land is fertile. Still, each year, the productivity of their land declines because of the scarcity of rainfall.

Economic factors

Farmers in the trays ecosystem received an average of 405690.400 FCFA as income after the sale of their harvest. For off-farm employment, 63% of farmers surveyed have stated they have off-farm employment. For them, agriculture only does not allow them to take care of their family because of the low price of the product and the low productivity of the crops.

Attitudinal factor

The farmers said that the reduction of rainfall is a big issue for the agricultural sector because it is one of the main determinants of land productivity. Around 91% reported a rainfall decrease. For temperature, 47% of farmers declared facing high temperatures.

Sustainable land management practices

Table 17 shows farmers' adoption of various SLM practices in their plots. Mulching is the most SLM practice adopted in the study area, with 88.4 % of adoption by farmers interviewed. The adoption of intercropping is estimated at 66.4%. The use of improved seed was the SLM practice, where the adoption was very low, estimated at 8.3%, according to the farmers interviewed. Crop rotation was adopted in just about 32 %, while fallow was done in 51.3%.

Also, combining the sustainable practices adopted in the study area, figure 11 shows the percentage of each sustainable land management practice.

Concerning the simultaneous adoption of the SLM practices, the possible number of SLM practices adopted ranged from 0 to 6 (Figure 12 see appendix A). About 1.91% of the farmers interviewed in the trays ecosystem did not use SLM practices in their farm plots.

Further, figure 12 shows that only one SLM practice was used in about 18.34%. Similarly, two SLM practices were applied by farmers at 26.75%. Farmers simultaneously adopted three SLM practices at 23.69%, while 20.76% used four SLM practices in the study area. Farmers who applied five SLM practices simultaneously accounted for 5.98% while those who applied six SLM practices simultaneously accounted for 2.55%.

Figure 13 (see appendix A) presents the type of crop practiced by farmers in the study area. Three kinds of farmers have been identified. These are those who cultivate cash crops only, those who specialise in producing food crops, and those who cultivate both crops. Of the 785 farmers interviewed, 22 percent said they grew cash crops, 30 percent food crops, and 48 percent both of them. The high percentage of those who practice the two types of culture is to minimize the risk of low prices of cash crops given by the government.

4.5.2 Multivariate probit (MVP) results and discussions

This subsection presented and discussed the results of the multivariate probit (MVP) regression. The MVP regression used the maximum likelihood to identify the determinant of simultaneous adoption of SLM practices. The MVP models are well-suited to the data (Table 18). At 1% level of significance, the Wald test [Chi2(102)=654.34; Prob>Chi2=0.000] rejects the hypothesis that all regression coefficient values are equal to zero.

Table 18: MVP results

	FALLOW		INTERCROP		MULCHING		FERTUSE		IMPSEED		CROPROTATION	
Variable	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
TEMPINC	-0.014	0.099	0.011	0.108	-0.203	0.134	-0.078	0.123	**0.276***	0.161	**0.199***	0.108
AGE	-2.56e-4	0.004	0.001	0.005	0.007	0.006	**-0.014****	0.006	**-0.017****	0.007	-0.001	0.004
LANDFER	**0.249****	0.098	**0.562*****	0.11	0.214	0.136	**-1.894*****	0.167	**-0.540*****	0.169	**0.234****	0.107
SLOPE	0.157	0.118	**0.626*****	0.141	**0.597*****	0.188	**0.310****	0.145	**0.539*****	0.16	**0.550*****	0.119
EDUCATION	0.146	0.098	-0.074	0.108	-0.017	0.136	0.064	0.123	-0.094	0.158	0.07	0.109
CREDAC	0.002	0.163	0.102	0.183	**-0.351***	0.203	0.076	0.203	0.07	0.245	0.042	0.174
INCOME	-8.92e-08	1.17e-07	5.65e-09	1.13e-05	4.64e-09	1.45e-07	**6.62e-07*****	1.51e-07	1.65e-07	1.53e-07	**-4.63e-07*****	1.72e-07
RAINFDEC	**0.563*****	0.176	**0.501*****	0.174	-0.223	0.221	**0.517****	0.243	4.422	111.714	**0.687*****	0.226
HHSIZE	0.022	0.014	0.016	0.015	0.003	0.018	**0.036****	0.018	0.016	0.022	0.004	0.015
MEMBSHIP	0.219	0.187	0.118	0.237	0.062	0.282	0.262	0.229	0.014	0.262	**0.404****	0.192
FARMEXP	**0.126***	0.07	0.109	0.074	**0.309*****	0.083	**-0.417*****	0.087	0.051	0.139	-0.041	0.077
OFFARMEMP	**-0.183***	0.101	**-0.587*****	0.116	-0.08	0.142	**-0.294****	0.125	**-0.369****	0.163	-0.128	0.109
TOTFARM	**0.163*****	0.032	**0.107*****	0.035	**0.156*****	0.054	**0.213*****	0.04	**0.083***	0.049	**0.250*****	0.033
ADVINF	**0.206***	0.105	**0.677*****	0.121	-0.221	0.147	**0.464*****	0.131	**0.987*****	0.173	**0.382*****	0.109
FSIZE	**-0.053****	0.024	-0.008	0.025	**-0.068****	0.028	**-0.086*****	0.03	0.039	0.04	-0.043	0.028
EROSION	**-0.192***	0.112	0.192	0.129	0.111	0.156	0.026	0.142	0.161	0.164	**0.250****	0.116
GENDER	-0.081	0.106	**0.237****	0.116	-0.03	0.146	-0.145	0.132	0.133	0.178	**-0.249****	0.115
_cons	-1.444***	0.339	-1.244	0.349	-0.166	0.412	0.552	0.418	-6.309	111.715	-1.82	0.384

Number of obs = 785 Log likelihood = -1923.6956 Wald chi2(102) = 654.34 Prob > chi2 = 0.0000

The likelihood ratio test [Chi2(15)=134.401; Prob>Chi2=0.000] is firmly rejected at a 1% level of significance. It is the test of the independence of residual terms, and its rejection means that the simultaneous adoptions of SLM practices are dependent.

The correlation matrices between the error terms of SLM practices (six regressions) are presented in Table 19 (see appendix A). The coefficients of correlation in ten of fifteen cases were significant and had positive signs. The positive cases indicate complementarity among the SLM practices (Etsay et al., 2019; Jerop et al., 2018; O. Kirui & Mirzabaev, 2015; Teklewold et al., 2013). On the other hand, intercropping is complementary to fertilizer use, fallow, mulching, crop rotation, and improved seed. Crop rotation is also complementary to fertilizer use, fallow, and mulching. The improved seed of his side is complementary to fertilizer use.

The MVP model results reveal that out of seventeen independent variables, eleven have a substantial effect on the adoption of SLM practices. These variables are interpreted below.

Perception of rainfall decrease

Based on the perception of rainfall decrease by farmers interviewed, it appeared that rainfall decrease, which is our interest variable, favorably influence fallow, intercropping, fertilizer use, and crop rotation respectively at 1%, 1%, 5%, and 1%. The meaning is that the more the rainfall decreases, the adoption of fallow, intercropping, fertilizer use, and crop rotation increase. The findings is in line with Zhang et al. (2017). The authors establish a positive influence of rainfall decrease on fallow adoption, meaning that more variation of rainfall increases the use of fallow. For crop rotation, the positive influence concord with the results of Wang et al. (2021). According to the authors, it might improve crop yield in adverse weather pattern such as decreased rainfall. However, the result contradicts the results found by Teklewold et al. (2013). For the authors, the adoption of fertilizer use and some SLM practices such as intercropping is high where rainfall is abundant. Therefore, our hypothesis that the decrease in rainfall determines the adoption of simultaneous SLM practices is verified for fallow, intercropping, fertilizer use, and crop rotation.

Perception of temperature increase

The perception of temperature increase positively affects the adoption of improved seed and crop rotation at 10% significance levels. This positive influence implies that the improved seed and crop rotation adoption increase when temperature increases. The possible explanation is that using ordinary seeds when the temperature increases affect reproductive processes. Adopting improved seeds adapted to resist change in weather is more profitable in increasing crop yields. These findings are similar to Kirui & Mirzabaev, (2015); Zhang et al. (2017). Concerning crop rotation, the positive influence is because it improves the climate resilience of agricultural productivity.

Age of farmer

Age of the farmer negatively influences fertilizer use and improved seed at 5% significance level. This finding reveals that older farmer probability to invest in SLM practices is low because they have a shorter horizon planning than the younger farmers. In addition, they may have larger families and more obligations, limiting their capacity to spend on fertilizers and improve seeds. Also, they could have had badly past experiences with improved seed and fertilizer adoption that could affect their future SLM adoption decision. The findings of Anley et al. (2007) corroborate the negative and significant influence of age on fertilizer use and improved seed. Similarly, Ghimire & Kafle (2014); Miheretu & Yimer (2017) observed this negative relationship between age and SLM practices. However, some authors, such as Dokyi et al. (2021); Islam et al. (2012), obtained contrary results arguing that elder farmers are more informed and recognize the benefits of implementing SLM measures.

Land fertility

Land fertility reduces fertilizer use and improved seed at 1% significance level but increases fallow, intercropping, and crop rotation adoption, respectively at 5%, 1%, and 5% significance levels. The negative influence of land fertility on fertilizer use and improved seed means that the need for fertilizer use and improved seed decrease when land fertility increases. In fact, farmers don't apply fertilizer and/or don't use improved seeds if they know that their lands are fertile. Applying fertilizer and/or using improved seed when their land is fertile constitute additional costs for them, above all, they are smallholder farmers. This finding agrees with Teklewold et al. (2013); Zhou et al. (2010). Conversely, the positive relationship in table 19 between land fertility and fallow, intercropping, and crop rotation involves that when land fertility increases, the adoption of fallow, intercropping, and crop rotation increases. The positive effect of intercropping concurs with the results of Ketema & Bauer (2012); Li et al. (2021), who discovered that intercropping helps sustain land fertility by increasing the soil nutrient components.

Slope

Slope positively influenced intercropping, mulching, fertilizer use, improved seed, and crop rotation. All SLM practices mentioned above were statistically significant at 1% except fertilizer which was significant at 5%. The favorable effect of slope on adopting SLM practices is because farmers are more willing to invest in SLM practices on their sloped field. This result agrees with Teklewold et al. (2013), who pointed out the propensity to use fertilizer and improved seed increase when field is on slope. Baderan et al. (2020) found that fertilizer use is higher when the plot is on a slope. As result of their study, they showed that slope and fertilizer use could increase the yield of crops (maize in its case). Wang et al. (2021) found a positive relationship between slope and crop rotation.

Similarly, Bakker et al. (2005); He et al. (2008) found the same results. The authors argued that soil erosion could incentivize farmers to adopt SLM practices as crop rotation. According to He et al. (2008), the positive correlation between the slope and soil erosion would motivate farmers to use corrective measures such as crop rotation. This fact is one reason for the slope's positive influence on crop rotation.

Access to credit

Assumed to favoring the adoption of SLM practices, access to credit reduces farmers' mulching adoption. It is statistically significant at 10%, meaning that increased access to credit reduces the mulching adoption by farmers. This result is inconsistent with Babalola & Olayemi (2014); Miheretu & Yimer (2017); Teklewold et al. (2013); Toma et al. (2017), who found a favorable effect of access to credit on farmers' decision to implement sustainable land management practices.

Farmer income

Farmer income had a positive influence on fertilizer use at 1% significance level, while it negatively influenced crop rotation at 1% significance. This positive influence of income on fertilizer use could be interpreted as farmer’s income determine decision to adopt SLM practices

(Dung, 2022). More their income increase, greater is the probability for them to use fertilizer on their farm because it is expensive. The finding for fertilizer use is in agreement with Zhang & Hu, (2020) work. However, the results contradict the findings of Bai et al. (2020), who established a negative influence between fertilizer use and farmers' income, but this negative influence decreases annually. Concerning crop rotation, the negative influence of farmers' income on it means that when farmer income increases, the adoption of crop rotation decreases. It could be interpreted by the fact that wealthy farmers can improve the fertility of their land by purchasing fertilizer or improved seeds and use them. Another explanation is that sometimes wealthy farmers specialize in cash crop production, necessitating the non-adoption of crop rotation.

Household size

The household size coefficient is positive and significantly influences fertilizer use at 5%, meaning that fertilizer use increases when the household size increases. The positive influence between household size and fertilizer use is supported by (Miheretu & Yimer, 2017), who stated that households with more family labor are inclined to use labor-intensive land management practices. One explanation could be that larger families sometimes include more children who are unproductive. Of this fact, fertilizer use is essential to improve the productivity of their farm. Another explanation is that an increase in household size increase food demand for the household. One alternative for the farmers is to use fertilizer to improve the productivity of their land to meet the food demand. Dung (2022) contests this positive relationship but argued that if the household contain more labor, the adoption of the SLM practices could be possible.

Membership

Membership plays an important role in the adoption of sustainable land management practices. It positively impacts the adoption of crop rotation at 5% level of significance. The positive impact means that farmers who belong to an association or cooperative have high propension to adopt crop rotation. It is because the farmer can easily share and disseminate SLM knowledge to each other members and also because of the imitation effect. The finding is consistent with Babalola & Olayemi (2014); He et al. (2008); Saguye (2017); Toma et al. (2017).

Farmer experience

Consistent with Zhang et al. (2017) and Dokyi et al. (2021), farmer experience positively influences the adoption of mulching and fallow, respectively, at 1% and 10% levels of significance. A plausible argument could be that experienced farmers see the necessity to manage their land better to keep them wet and to improve their yield. Also, more experienced farmers seem to have extensive knowledge of the methods and functioning of agricultural production Ahmed et al. (2017). In addition, experienced farmers can easily evaluate the advantage of mulching and fallowing in their fields. Regarding fertilizer use, farmer experience negatively affects it at 1% level of significance. The explanation is that fertilizers sometimes cause various plant diseases, as was the case for some crops (cassava, coconut palm, etc.) in the country's coastal zone, where some farmers claimed to have lost their trees after spreading fertilizers in their fields.

Off-farm employment

Off-farm employment negatively influences all the SLM practices in the study except mulching and crop rotation, which are insignificant. The significance level is 10%, 1%, 5%, and 5% for fallow, intercropping, fertilizer use, and improved seed. It means that SLM practices other than mulching and crop rotation are less likely to be adopted when farmers have off-farm employment. This is because farmers who have off-farm work may have time constraints to work and adopt some SLM practices on their farms. The results corroborate those found by Saguye (2017); Amsalu & de Graaff (2007); Tenge et al. (2004). However, Ketema & Bauer (2012) found the opposite result about some SLM practices as intercropping. For the authors, the positive link between off-farm employment and intercropping could be explained by the fact that intercropping does not require more labor input.

Total farmland

Table 18 shows that total farms positively influenced the adoption of all SLM practices. The significance level for all SLM practices is 1% except for improved seed, which is significant at 10%. The probability of adopting one of the SLM practices is positively affected by the number of farmland possessed by farmers implying that the adoption of sustainable land management increases when the total farmland increases. Babalola & Olayemi (2014) found the same results. Also, Teferra et al. (2019) agreed with the result concerning the positive influence of total farms on crop rotation. The findings of Hong et al. (2020) concur with our conclusions concerning intercropping.

Advice and information about SLM practices

The results (Table 18) also show that access to advice and information about SLM practices positively influences the adoption of fallow, intercropping, fertilizer use, improved seed, and crop rotation, respectively at 10%, 1%, 1%, 1%, and 1% level of significance. As an explanation, the adoption of any SLM practices except mulching increase when farmers receive advice and information about SLM practices. Indeed, advice and information from extension contacts about SLM practices help farmers enhance their land's productivity by introducing new practices. The positive influence of advice and information on intercropping is close to the findings of Ketema & Bauer (2012); Saguye (2017).

Farm size

According to the result, farm size negatively influenced fallow, mulching, and fertilizer use, respectively at 5%, 5%, and 1%, implying that per hectare fertilizer use, fallow, and mulching decrease when farm size increases. For fertilizer use, this could be explained by the fact that fertilizer is expensive, and more the farm size increase, more the need for fertilizer also increase, and more the smallholder farmers face money constraints. Several studies have found a negative influence of farm size on fertilizer use Hu et al. (2019; Wu et al. (2018); Zhang & Hu (2020); Zhou et al. (2010). However, this result is in contraction with Babalola & Olayemi (2014); Ahmed et al. (2017), who established a positive relationship. According to the authors, in rural areas, land can represent wealth and, thus, indicate the ability to buy inputs like improved seed, fertilizer, etc.

Regarding the fact that farm size reduces the adoption of mulching, one possible explanation is that mulching was commonly used by small farmers. The findings agree with those found by Babalola & Olayemi (2014). Jama et al. (2019) suggested that the negative relationship between fallow and farm size could be explained by the difficulty in managing larger farms owned by farmers. As a result, farmers' participation in additional agricultural activities is reduced.

Erosion

The influence of erosion on fallow adoption was negative at 10% but positive with crop rotation at 5% levels of significance. The positive relationship between soil erosion and crop rotation means that the adoption of crop rotation increases with more soil erosion. The outcome is in agreement with the finding of Jankauskas et al. (2004), who found that crop rotation decreases the rate of soil erosion. The negative relationship between erosion and fallow implies that when erosion increases, keeping the other variables constant in the model constant, the fallow adoption decreases. The explanation could be that more significant amounts of crop residues that improve soil quality remain on the plot during fallow periods.

Gender

In line with Kirui & Mirzabaev (2015) results, gender had a favorable and substantial impact on intercropping at 5% level of significance. Due to their implication in extension services (knowledge exchanges, advice and information) about SLM practice more frequently than women, men had a high probability of adopting intercropping (Salaisook et al., 2020). This positive relationship is corroborated by Gebreselassie et al. (2013), who found that men are more likely to adopt SLM practices because of cultural and social setups that allow them to control land and other external inputs. Conversely, the adoption of crop rotation is reduced at 5% level of significance when farmers are men, keeping other variables constant in the model. That is because male farmers are more specialized in cash crops that do not necessitate crop rotation than food crops. Another explanation is that female farmer adopted crop rotation more than males because they are focused on food crops. The results concur with Jerop et al., (2018), who found that men leave SLM practices, seedings, transplanting, land preparation, picking, and threshing to women.

4.6 Conclusion

Increasing agricultural productivity and reducing the rate of land degradation through the adoption of SLM practices is important to achieve food security and increase farmers' income in Cote d'Ivoire. In this study, we used MVP model to identify the determinant of the simultaneous adoption of SLM practices under a changing climate in Cote d'Ivoire. Our approach considers correlations between SLM practices and includes several policy-relevant variables influencing adoption decisions. The SLM practices considered in this study included fallow, crop rotation intercropping, improved seed mulching, and fertilizer use. The results establish complementarities between the SLM practices, reflecting their interdependence. A set of factors determines the simultaneous adoption of SLM practices; demographic, institutional, physical, economic, and attitudinal characteristics. Excepted education, all variables included in the model influence the adoption of SLM practices, taking into account the results from each SLM Practice. These are temperature increase, age, land fertility, slope, access to credit, income, rainfall decrease, household size, membership, farmer experience, off-farm employment, total farm, advice and information, farm size, erosion, and sex. Thus, the hypothesis we formulated in this study, which states that the decrease in precipitation determines the adoption of simultaneous SLM practices, is verified for four SLM practices (fallow, intercropping, fertilizer use, and crop rotation).

Referring to the findings, the significant role of institutional factors could suggest the need for establishing and strengthening local agricultural institutions to promote the adoption of SLM practices. In a country where agriculture occupies a great place in GDP formation and employs 2/3 labor force, local agricultural institutions can play an important role by providing advice and information to farmers about SLM practices. Also, they could subsidize some inputs to facilitate their access to farmers, facilitate access to credit that helps them to adopt SLM practices easily, and allow technical assistance to farmers who adopt some SLM practices.

Although this study provides evidence on factors influencing the simultaneous adoption of SLM practices, it uses cross-sectional data collected randomly from farmers in trays ecosystems. Future research must consider all ecosystems to identify better the determinants of the simultaneous adoption of SLM practices in the country. Another recommendation can be to employ panel data to capture the dynamic of the adoption of SLM practices by farmers.

GENERAL CONCLUSION

This study aimed to analyze the economic impact of land degradation in the tray ecosystem in Ivory Coast. The first chapter related the links between climate change and land degradation. It presented an overview of land degradation and some policy and commitment set up to reverse the negative trend of land degradation and vegetation loss in the country, the types of land degradation and the direct linkage of land degradation with climate change. In the second chapter, through primary data collected from farmers, we identified the drivers of land degradation using logistic regression. The results obtained from the regression showed that gender and education reduce land degradation while slope, erosion, pesticide use, agricultural activities, deforestation, and temperature exacerbate land degradation. The third chapter used an instrumental variable (two-stage least squares) to estimate the net income loss by farmers due to land degradation. According to the results, soil organic matter, education, and property rights positively affect the net farming income. Other variables, like the plot on slope, erosion, and farm size, negatively affect the net farming income. Also, the results found that reducing soil organic matter, a determinant element in soil fertility, reduces the net farming income by 0.07 unit. The last chapter has identified the determinants of the simultaneous adoption of sustainable land management practices under a changing climate in the ecosystem. The adoption of sustainable land management practices is crucial to reverse the trend of land degradation. A multivariate probit model is used to identify the determinants of simultaneous adoption of SLM practices. As findings, eleven of seventeen independent variables significantly influence the adoption of SLM practices. Also, the correlation matrices between the error terms of SLM practices were statistically significant in ten cases out of the fifteen cases where all the ten coefficients have positive signs meaning complementarity among them.

For a country like Ivory Coast, where the agriculture sector accounts for twenty-three percent of its GDP formation and employs two-thirds of the active population, it is very urgent to implement some policies and strategies to reverse the negative trend of land degradation. Despite the efforts made by the government, non-governmental organizations, and community leaders in charge of combatting land degradation and climate change to improve the population's well-being, the consequences of land degradation are enormous. Food insecurity, income reduction, increase in commodity price and poverty rate, migration, reduction of the arable land, and conflict are some of the socioeconomic consequences while reduction of biodiversity, erosion, the prevalence of invasive species, and air pollution through the death of plants and trees are some environmental consequences. Taking into account the commitments made by the Ivorian government and participants at COP15 [17] to restore one billion hectares of degraded land by 2030, there is hope to cope with land degradation in the world. Especially with the funding obtained at this COP by the Ivorian government, particular attention must be made to the degraded land in Cote d'Ivoire.

POLICY IMPLICATIONS

A scientific research aims to propose some policy implications that can be applicable to improve populations' and countries well-being. Given the findings from this dissertation, we formulate some recommendations. These are :

- Increase the protected area and allow their proper functioning to deter illegal exploitation: Actually in the country, the remain forest are found in some protected areas. Increasing and allowing their well-functioning will help recover the vegetation cover more benefit for life. The intensification of afforestation is another way to recover the vegetation.
- Raising awareness to the population about the benefits of forests and protected areas and the negative effect of pesticide use on land in the long run: population must know that protected areas contribute to water security, public health, resilient cities, and disaster risk reduction to facilitate their implementation. Conversely, pesticide use can degrade their land because of chemical content that takes some time to dissipate.
- Implementing good land tenure policy: it will help farmers safely invest in sustainable practices in their land because without good policy their land may escape to them anytime. Good land tenure policy reduces conflicts about land.
- Establishing and strengthening local agricultural institutions in research and innovation to help farmers improve the productivity of their land through sustainable land management practices but also adapt and mitigate the climate change impact. Also, local agricultural institutions must promote the adoption of SLM by providing advice and information to farmers.
- Improving farm management skills and making information available on SLM practices.

[17] Fifteenth session of the conference of parties COP15 of the United Nations Convention to Combat Desertification (UNCCD) held in Abidjan from 09 May to 20 May 2022

- Facilitate access to credit or subsidize farm inputs as much as possible to allow farmers to afford them. Taking the case of fertilizer and improved seeds, because of their high price, a few part of farmer buy them.

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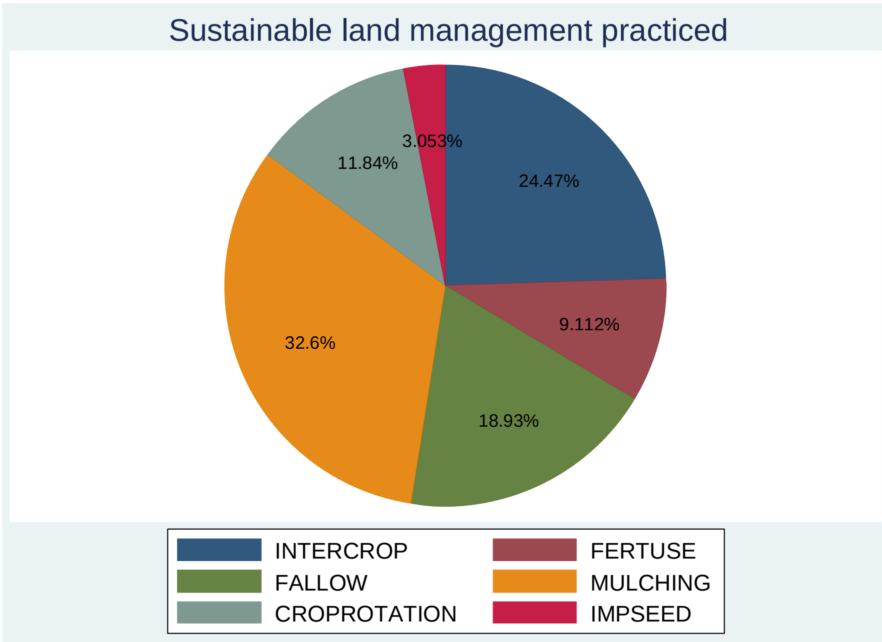
APPENDICES

➢ APPENDIX A

Table 17: Descriptive statistics of the variables

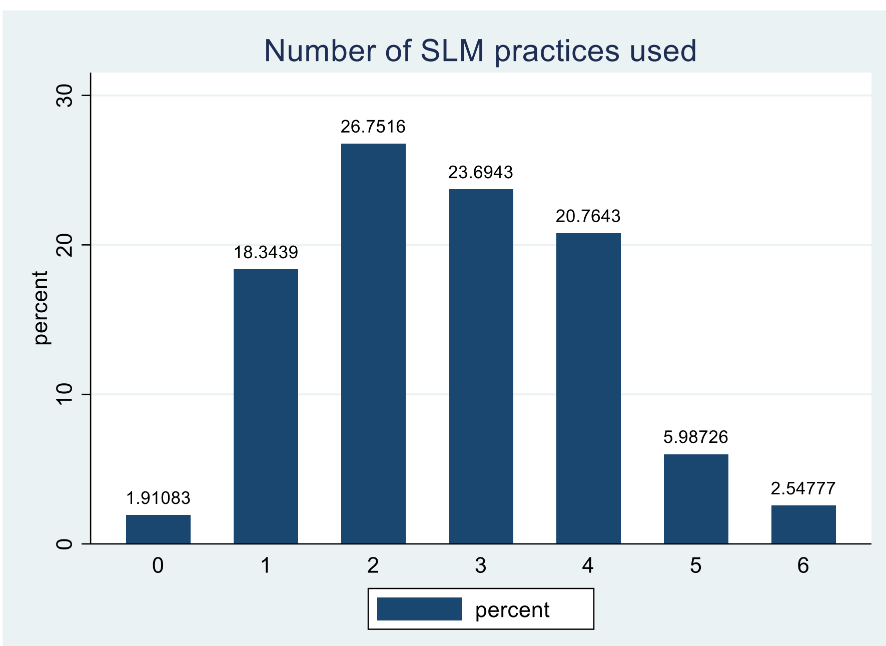
Variable	Mean	Std. Dev.	Min	Max
GENDER	0.659	0.474	0	1
AGE	46.540	12.710	20	91
EDUCATION	0.483	0.500	0	1
HHSIZE	7.246	3.649	1	25
OFFARMEMP	0.631	0.483	0	1
FARMEXP	3.628	0.724	1	4
CREDAC	0.096	0.294	0	1
MEMBSHIP	0.074	0.262	0	1
ADVINF	0.380	0.486	0	1
TOTFARM	2.696	1.566	1	14
PROPRIGHT	0.192	0.394	0	1
FSIZE	2.291	2.300	0.25	16
SLOPE	0.275	0.447	0	1
LANDFER	0.422	0.494	0	1
INCOME	405690.400	473561.600	20000	5700000
INTERCROP	0.664	0.473	0	1
FERTUSE	0.247	0.432	0	1
FALLOW	0.513	0.500	0	1
IRRIGATION	0.054	0.225	0	1
MULCHING	0.884	0.320	0	1
CROPROTATION	0.321	0.467	0	1
IMPSEED	0.083	0.276	0	1
RAINFDEC	0.910	0.287	0	1
TEMPINC	0.473	0.500	0	1
EROSION	0.304	0.460	0	1

Figure 11: Proportion of SLM practices used



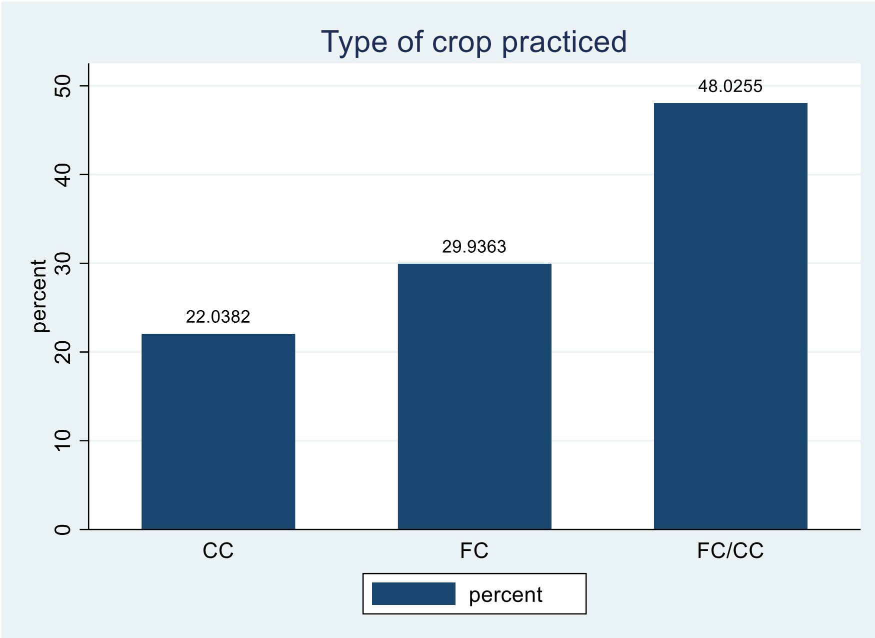
Source: Author compilation

Figure 12: Number of SLM practices adopted by farmers



Source: Author compilation

Figure 13: Type of crops practiced by farmers in the Tray ecosystem



Source: author compilation

Table 19: Covariance matrix of the regression equations between SLM practices

	INTERCROP	FERTUSE	FALLOW	MULCHING	CROPROTATION	IMPSEED
INTERCROP	1					
FERTUSE	0.114*** 0.0014	1				
FALLOW	0.1647*** 0.0000	0.0556 0.1198	1			
MULCHING	0.0791** 0.0266	-0.0047 0.8951	-0.0182 0.6112	1		
CROPROTATION	0.3797*** 0.0000	0.1121*** 0.0017	0.2818*** 0.0000	0.1126*** 0.0016	1	
IMPSEED	0.1747*** 0.0000	0.3422*** 0.0000	-0.0034 0.9239	0.0366 0.3057	0.1399*** 0.0001	1

Likelihood ratio test of ρ(INTERCROP)(FALLOW)=ρ(MULCHING)(FALLOW)=ρ(FERTUSE)(FALLOW)= ρ(IMPSEED)(FALLOW)= ρ(CROPROTATION)(FALLOW)= ρ(MULCHING)(INTERCROP)= ρ(FERTLUSE)(INTERCROP)= ρ(IMPSEED)(INTERCROP)= ρ(CROPROTATION)(INTERCROP)= ρ(FERTUSE)(MULCHING)= ρ(IMPSEED)(MULCHING)= ρ(CROPROTATION)(MULCHING)= ρ(IMPSEED)(FERTUSE)= ρ(CROPROTATION)(FERTUSE)= ρ(CROPROTATION)(IMPSEED)=0 : Chi2(15)= 134.401 ; Prob>Chi2 = 0.0000

*, **, and *** indicate statistical significance at 10, 5, and 1% significance levels.

Source: Author's compilation.

➢ APPENDIX B: RESULT OF REGRESSIONS AND DIAGNOSTIC TESTS

• RESULT OF LOGISTIC REGRESSION

```
Logistic regression                             Number of obs     =        780
                                                LR chi2(11)       =      75.20
                                                Prob > chi2       =     0.0000
Log likelihood = -502.12901                     Pseudo R2         =     0.0697
```

LD	Odds Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
GENDER	.264893	.0601148	-5.85	0.000	.1697849	.4132777
AGE	.9978272	.0061046	-0.36	0.722	.9859338	1.009864
EDUCATION	.6953706	.1244878	-2.03	0.042	.4895884	.9876466
HHSIZE	1.013801	.0212269	0.65	0.513	.9730391	1.05627
SLOPE	2.641564	.6901798	3.72	0.000	1.582931	4.408192
EROSION	1.399416	.2358934	1.99	0.046	1.005689	1.947288
PESTICID	1.30823	.2092203	1.68	0.093	.9562126	1.789837
AGRIACT	1.978164	.4614802	2.92	0.003	1.252241	3.124904
DEFOR	1.574912	.276787	2.58	0.010	1.115988	2.222557
TEMP	1.23631	.0618443	4.24	0.000	1.12085	1.363664
PRECI	1.010075	.0079409	1.28	0.202	.9946303	1.025759
_cons	.0042152	.0055043	-4.19	0.000	.0003261	.0544925

Note: _cons estimates baseline odds.

```
Marginal effects after logistic
      y  = Pr(LD) (predict)
         =  .52805794
```

variable	dy/dx	Std. Err.	z	P>|z|	[95%	C.I.]	X
GENDER*	-.3137488	.04869	-6.44	0.000	-.409173	-.218325	.646154
AGE	-.0005421	.00152	-0.36	0.722	-.00353	.002446	49.2205
EDUCAT~N*	-.0905237	.04443	-2.04	0.042	-.177606	-.003441	.326923
HHSIZE	.0034158	.00522	0.65	0.513	-.006812	.013643	7.42308
SLOPE*	.2251886	.05341	4.22	0.000	.120515	.329862	.111538
EROSION*	.0833929	.04154	2.01	0.045	.001977	.164809	.408974
PESTICID*	.0667293	.03952	1.69	0.091	-.010725	.144183	.387179
AGRIACT*	.1689038	.05669	2.98	0.003	.057803	.280005	.65
DEFOR*	.1130602	.0434	2.61	0.009	.027999	.198121	.720513
TEMP	.0528659	.01246	4.24	0.000	.028437	.077295	25.3791
PRECI	.0024982	.00196	1.28	0.202	-.001342	.006338	5.95517

(*) dy/dx is for discrete change of dummy variable from 0 to 1

- **Hosmer-Lemeshow goodness of fit test**

```
. lstat

Logistic model for LD

              -------- True --------
Classified |         D            ~D  |      Total
-----------+--------------------------+-----------
     +     |       256           155  |        411
     -     |       153           216  |        369
-----------+--------------------------+-----------
   Total   |       409           371  |        780

Classified + if predicted Pr(D) >= .5
True D defined as LD != 0
--------------------------------------------------
Sensitivity                     Pr( +| D)   62.59%
Specificity                     Pr( -|~D)   58.22%
Positive predictive value       Pr( D| +)   62.29%
Negative predictive value       Pr(~D| -)   58.54%
--------------------------------------------------
False + rate for true ~D        Pr( +|~D)   41.78%
False - rate for true D         Pr( -| D)   37.41%
False + rate for classified +   Pr(~D| +)   37.71%
False - rate for classified -   Pr( D| -)   41.46%
--------------------------------------------------
Correctly classified                        60.51%
--------------------------------------------------
```

- **Discriminating power test: the ROC curve**

```
. lroc

Logistic model for LD

number of observations =      780
area under ROC curve   =   0.6648

.
. estat gof, group(10) table
```

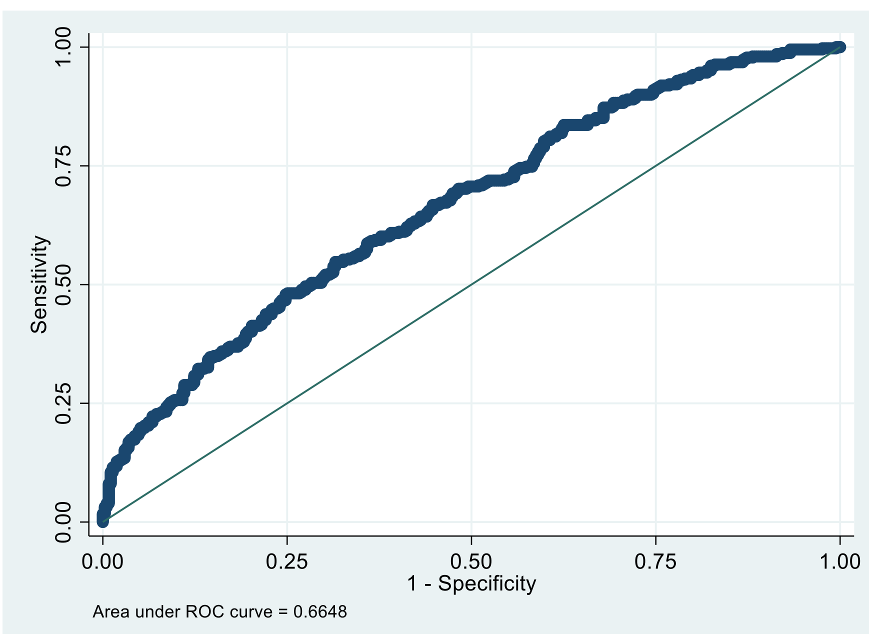
Logistic model for LD, goodness-of-fit test

(Table collapsed on quantiles of estimated probabilities)

Group	Prob	Obs_1	Exp_1	Obs_0	Exp_0	Total
1	0.3282	15	20.9	63	57.1	78
2	0.3943	32	28.6	46	49.4	78
3	0.4381	38	32.6	40	45.4	78
4	0.4720	37	35.7	41	42.3	78
5	0.5120	41	38.4	37	39.6	78
6	0.5605	40	42.0	38	36.0	78
7	0.6133	44	45.9	34	32.1	78
8	0.6640	47	49.7	31	28.3	78
9	0.7207	50	53.9	28	24.1	78
10	0.9575	65	61.5	13	16.5	78

```
      number of observations =       780
            number of groups =        10
      Hosmer-Lemeshow chi2(8) =        7.58
                  Prob > chi2 =        0.4754

.
```



- **Instrumental variables (2sls) regression results**

```
. ivregress 2sls NETLINCOME1 GENDER AGE EDUCATION HHSIZE PLOTSLOP EROSION ADVINF PESTICID PROPRIGH
> T FSIZE FSIZESQ (SOM= TEMP PRECI), vce(robust)

Instrumental variables (2SLS) regression          Number of obs   =        780
                                                  Wald chi2(12)   =     333.80
                                                  Prob > chi2     =     0.0000
                                                  R-squared       =     0.1180
                                                  Root MSE        =     .11812
```

NETLINCOME1	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
SOM	.0697334	.006065	11.50	0.000	.0578462	.0816205
GENDER	.0020703	.0107272	0.19	0.847	-.0189546	.0230951
AGE	-.0002097	.0004112	-0.51	0.610	-.0010157	.0005963
EDUCATION	.0163257	.0087767	1.86	0.063	-.0008763	.0335277
HHSIZE	.0006078	.0010449	0.58	0.561	-.0014402	.0026557
PLOTSLOP	-.0299512	.0156216	-1.92	0.055	-.060569	.0006666
EROSION	-.1156346	.0109839	-10.53	0.000	-.1371626	-.0941067
ADVINF	-.0063343	.0086642	-0.73	0.465	-.0233159	.0106473
PESTICID	-.0047592	.0094586	-0.50	0.615	-.0232976	.0137792
PROPRIGHT	.106699	.0115951	9.20	0.000	.083973	.129425
FSIZE	-.0269252	.0041528	-6.48	0.000	-.0350645	-.0187859
FSIZESQ	.0016913	.0003193	5.30	0.000	.0010655	.0023171
_cons	.8103345	.0341828	23.71	0.000	.7433375	.8773316

```
Instrumented:  SOM
Instruments:   GENDER AGE EDUCATION HHSIZE PLOTSLOP EROSION ADVINF PESTICID
               PROPRIGHT FSIZE FSIZESQ TEMP PRECI
```

- **Endogeneity test of endogenous regressors**

```
. estat endog

  Tests of endogeneity
  Ho: variables are exogenous

  Robust score chi2(1)            =  35.8959  (p = 0.0000)
  Robust regression F(1,766)      =  40.4949  (p = 0.0000)
```

- **Overidentification test**

```
. estat overid

  Test of overidentifying restrictions:

  Score chi2(1)           =  .156998  (p = 0.6919)
```

- **Underidentification test**

```
. estat firststage, forcenonrobust

  First-stage regression summary statistics
  ------------------------------------------------------------------------
               |            Adjusted      Partial       Robust
      Variable |   R-sq.       R-sq.        R-sq.     F(2,766)   Prob > F
  -------------+----------------------------------------------------------
           SOM |  0.4050      0.3949       0.3763      279.105    0.0000
  ------------------------------------------------------------------------


  Minimum eigenvalue statistic = 231.077

  Critical Values                      # of endogenous regressors:    1
  Ho: Instruments are weak             # of excluded instruments:     2
  ---------------------------------------------------------------------
                                     |    5%     10%     20%     30%
  2SLS relative bias                 |         (not available)
  -----------------------------------+---------------------------------
                                     |   10%     15%     20%     25%
  2SLS Size of nominal 5% Wald test  |  19.93   11.59    8.75    7.25
  LIML Size of nominal 5% Wald test  |   8.68    5.33    4.42    3.92
  ---------------------------------------------------------------------
```

- **Multivariate probit result**

```
Multivariate probit (MSL, # draws = 5)          Number of obs    =        785
                                                Wald chi2(102)   =     654.34
Log likelihood = -1923.6956                     Prob > chi2      =     0.0000
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
FALLOW						
TEMPINC	-.0135578	.098861	-0.14	0.891	-.2073217	.1802062
AGE	-.0002557	.0040908	-0.06	0.950	-.0082734	.0077621
LANDFER	.2491649	.0984564	2.53	0.011	.056194	.4421358
SLOPE	.1572755	.1177965	1.34	0.182	-.0736014	.3881525
EDUCATION	.1461416	.0981959	1.49	0.137	-.0463189	.3386021
CREDAC	.0021112	.1626913	0.01	0.990	-.3167578	.3209803
INCOME	-8.92e-08	1.17e-07	-0.76	0.445	-3.18e-07	1.40e-07
RAINFDEC	.5632302	.1755513	3.21	0.001	.219156	.9073044
HHSIZE	.0222461	.0137585	1.62	0.106	-.00472	.0492122
MEMBSHIP	.2193204	.1866526	1.18	0.240	-.1465118	.5851527
FARMEXP	.1263031	.0703941	1.79	0.073	-.0116669	.2642731
OFFARMEMP	-.1832808	.1013492	-1.81	0.071	-.3819217	.01536
TOTFARM	.1630254	.0324335	5.03	0.000	.0994569	.2265939
ADVINF	.205696	.1046665	1.97	0.049	.0005534	.4108386
FSIZE	-.053087	.0243294	-2.18	0.029	-.1007718	-.0054023
EROSION	-.1921099	.112204	-1.71	0.087	-.4120258	.027806
GENDER	-.0808179	.1061923	-0.76	0.447	-.2889511	.1273152
_cons	-1.444094	.3389054	-4.26	0.000	-2.108336	-.7798513
INTERCROP						
TEMPINC	.0107487	.1083706	0.10	0.921	-.2016539	.2231513
AGE	.0013756	.0045369	0.30	0.762	-.0075165	.0102676
LANDFER	.5617903	.1104091	5.09	0.000	.3453924	.7781882
SLOPE	.6258916	.1412037	4.43	0.000	.3491375	.9026457
EDUCATION	-.0739998	.1083211	-0.68	0.495	-.2863052	.1383055
CREDAC	.1016164	.1831565	0.55	0.579	-.2573638	.4605966
INCOME	5.65e-09	1.13e-07	0.05	0.960	-2.16e-07	2.27e-07
RAINFDEC	.500834	.1740719	2.88	0.004	.1596594	.8420087
HHSIZE	.0163199	.0150132	1.09	0.277	-.0131054	.0457451
MEMBSHIP	.118432	.2367467	0.50	0.617	-.3455829	.5824469
FARMEXP	.1094335	.0740257	1.48	0.139	-.0356543	.2545213
OFFARMEMP	-.5872548	.1164508	-5.04	0.000	-.8154942	-.3590154
TOTFARM	.1071445	.0351503	3.05	0.002	.0382512	.1760378
ADVINF	.6768142	.1205632	5.61	0.000	.4405146	.9131138
FSIZE	-.0078203	.0252578	-0.31	0.757	-.0573247	.0416842
EROSION	.1919251	.1291791	1.49	0.137	-.0612613	.4451114
GENDER	.2370736	.1163294	2.04	0.042	.0090722	.465075
_cons	-1.244243	.3485096	-3.57	0.000	-1.927309	-.5611766

MULCHING						
TEMPINC	-.2034575	.1336343	-1.52	0.128	-.4653758	.0584609
AGE	.0065644	.0055489	1.18	0.237	-.0043111	.01744
LANDFER	.2143506	.1358105	1.58	0.114	-.051833	.4805343
SLOPE	.5971964	.1875464	3.18	0.001	.2296122	.9647807
EDUCATION	-.0173442	.135629	-0.13	0.898	-.2831723	.2484838
CREDAC	-.3511234	.2026447	-1.73	0.083	-.7482997	.0460528
INCOME	4.64e-09	1.45e-07	0.03	0.975	-2.81e-07	2.90e-07
RAINFDEC	-.2234741	.2213053	-1.01	0.313	-.6572246	.2102764
HHSIZE	.0033422	.0184677	0.18	0.856	-.0328538	.0395383
MEMBSHIP	.0621697	.2819199	0.22	0.825	-.4903831	.6147225
FARMEXP	.3091853	.0825743	3.74	0.000	.1473427	.4710279
OFFARMEMP	-.0802779	.1416138	-0.57	0.571	-.3578359	.1972801
TOTFARM	.1564845	.0537406	2.91	0.004	.0511549	.261814
ADVINF	-.2210158	.1466508	-1.51	0.132	-.508446	.0664144
FSIZE	-.0683265	.0284659	-2.40	0.016	-.1241186	-.0125345
EROSION	.1114515	.1563593	0.71	0.476	-.1950071	.41791
GENDER	-.0298659	.1464154	-0.20	0.838	-.3168349	.257103
_cons	-.1658991	.4119637	-0.40	0.687	-.9733332	.641535
FERTUSE						
TEMPINC	-.077976	.1228492	-0.63	0.526	-.318756	.162804
AGE	-.0142905	.0055947	-2.55	0.011	-.0252559	-.0033251
LANDFER	-1.89369	.1673107	-11.32	0.000	-2.221613	-1.565767
SLOPE	.3095303	.1451611	2.13	0.033	.0250199	.5940408
EDUCATION	.0641842	.123233	0.52	0.602	-.177348	.3057163
CREDAC	.0762391	.2033044	0.37	0.708	-.3222303	.4747084
INCOME	6.62e-07	1.51e-07	4.39	0.000	3.66e-07	9.57e-07
RAINFDEC	.5169326	.2433701	2.12	0.034	.039936	.9939292
HHSIZE	.0355574	.017538	2.03	0.043	.0011836	.0699312
MEMBSHIP	.2622847	.2291671	1.14	0.252	-.1868744	.7114439
FARMEXP	-.416755	.0865105	-4.82	0.000	-.5863125	-.2471974
OFFARMEMP	-.2944942	.1251627	-2.35	0.019	-.5398086	-.0491798
TOTFARM	.212974	.0400063	5.32	0.000	.1345632	.2913849
ADVINF	.4640506	.1313257	3.53	0.000	.2066569	.7214443
FSIZE	-.0855663	.0297755	-2.87	0.004	-.1439252	-.0272073
EROSION	.0264063	.1415361	0.19	0.852	-.2509994	.303812
GENDER	-.144658	.1318816	-1.10	0.273	-.4031411	.1138251
_cons	.5518129	.4176092	1.32	0.186	-.266686	1.370312

/atrho21	.106603	.0620734	1.72	0.086	-.0150586	.2282646
/atrho31	-.2413419	.0788781	-3.06	0.002	-.3959401	-.0867438
/atrho41	.1155205	.0684851	1.69	0.092	-.0187077	.2497488
/atrho51	-.1003193	.0873512	-1.15	0.251	-.2715245	.0708859
/atrho61	.2951108	.0649763	4.54	0.000	.1677597	.422462
/atrho32	-.0335721	.0768049	-0.44	0.662	-.1841069	.1169628
/atrho42	.2553023	.076284	3.35	0.001	.1057884	.4048162
/atrho52	.2629634	.112611	2.34	0.020	.0422499	.4836769
/atrho62	.481845	.0783875	6.15	0.000	.3282084	.6354817
/atrho43	.0955317	.0912588	1.05	0.295	-.0833323	.2743957
/atrho53	.0131229	.1203867	0.11	0.913	-.2228306	.2490764
/atrho63	-.0094128	.081554	-0.12	0.908	-.1692558	.1504302
/atrho54	.5120302	.1327036	3.86	0.000	.251936	.7721245
/atrho64	.2887517	.0752991	3.83	0.000	.1411681	.4363353
/atrho65	.1250536	.0810971	1.54	0.123	-.0338937	.2840009
rho21	.106201	.0613733	1.73	0.084	-.0150574	.224381
rho31	-.2367629	.0744564	-3.18	0.001	-.3764698	-.0865269
rho41	.1150094	.0675792	1.70	0.089	-.0187055	.2446825
rho51	-.0999841	.086478	-1.16	0.248	-.2650428	.0707674
rho61	.286832	.0596305	4.81	0.000	.1662034	.3990025
rho32	-.0335595	.0767184	-0.44	0.662	-.1820546	.1164323
rho42	.2498964	.0715202	3.49	0.000	.1053956	.3840623

rho52	.2570652	.1051694	2.44	0.015	.0422248	.4491835
rho62	.44772	.0626745	7.14	0.000	.31691	.5618152
rho43	.0952422	.090431	1.05	0.292	-.0831399	.2677103
rho53	.0131221	.1203659	0.11	0.913	-.2192143	.2440503
rho63	-.0094125	.0815468	-0.12	0.908	-.1676578	.1493057
rho54	.4715256	.1031988	4.57	0.000	.2467377	.6481631
rho64	.2809855	.069354	4.05	0.000	.1402378	.4106022
rho65	.1244057	.0798419	1.56	0.119	-.0338808	.2766039

```
Likelihood ratio test of  rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 =
> rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0:
             chi2(15) =  134.401   Prob > chi2 = 0.0000
```

➢ APPENDIX C: SURVEY QUESTIONNAIRE

TOPIC: **Drivers of land degradation in trays as modulated under a changing climate: a case study of Cote d'Ivoire**

INTRODUCTION: Ce questionnaire vous est adressé pour une étude économique sur les facteurs de dégradation des terres en Côte d'Ivoire. Vos réponses seront analysées sans aucune référence à votre identité et seront utilisées pour rédiger les différents chapitres d'une thèse de doctorat en économie. Les objectifs de ce questionnaire sont les suivants :

- Connaitre la perception des agriculteurs sur la dégradation des terres.
- Identifier les facteurs de la dégradation des terres
- Identifier les conséquences de la dégradation des terres.
- Connaitre les pratiques et techniques adoptées par les agriculteurs pour la gestion durable de leur terre.

En nous aidant à répondre aux différentes questions posées dans ce questionnaire, vous encouragerez la recherche dans un domaine important pour l'avenir de nos pays et pour l'humanité.

Merci pour votre aide !

Fiche numéro ……….

A- IDENTIFICATION DE L'ENQUETEUR

A1- Nom de l'enquêteur :…………………………………………………………………..

A2- Code de l'enquêteur :…………………………………………………….……….

A3- Date de l'interview :………/………………/……………………………………….

A4- Début de l'interview :………h……………mn …………………………………….

A4- Fin de l'interview :………....h……………mn……………….…………………….

B- SITUATION GEOGRAPHIQUE

B1- Région :…………………………………………………………………………….

B2- Ecosystème :……………………………………………………………………….

B3- Nom du village :………………………………………………………………..

B4- Code du village :………………………………………………………………..

B5-Coordonnees GPS du village : Long……………………/Lat……………...………….

C- CARACTERISTIQUES SOCIODEMOGRAPHIQUES DU REPONDANT

C1- Nom du répondant :……………………………………………………….

C2- Numéro de téléphone :………………………………………………………..

C3- Sexe : 1- Masculin 2- Féminin ☐

C4- Date de naissance:………………………………………………………..

C5- Situation matrimoniale ☐

1- Célibataire 2- Marié 3- Divorcé/Séparé 4- Veuf/Veuve 5- Concubinage

C6- Nationalité du ménage ☐

1- Ivoirien 2- Non Ivoirien Si 2 aller à C9

C7- Si Ivoirien, quel est le groupe ethnique ☐

1- Akan 2- Gour 3- Krou 4- Mandé

C8- Quelle est votre origine? ☐

1- Autochtone 2- Allogène

C9- Quelle est votre religion? ☐

1-Chrétien 2- Musulman 3- Bouddhiste

4- Animiste 5- Sans religion 6- Autre à préciser :…………………………………………….

C10- Savez-vous lire et écrire?

1- Oui 2- Non Si non aller à C13

C11- Quel est votre niveau d'étude? ……………………………………………

C12- Quel est le dernier diplôme obtenu?

1-Aucun 2- CEPE 3- BEPC 4- BEP 5- CAP 6- BAC

7- BT 8- BTS 9- LICENCE 10-DUT 11- MAITRISE

12- MASTER/DEA/DESS 13- INGENIEUR 14- DOCTORAT 15- AUTRES

C13- Quel est le nombre de personne dans votre ménage?..

C14- Quel est le nombre de personne actif dans le ménage (supérieur ou égal à 18 ans) ?..

C15- Etes-vous le chef de ménage ?

1- Oui 2- Non

D- <u>ACTIVITES ECONOMIQUES DU REPONDANT</u>

D1- Quelles sont vos activités économiques?

1-Agriculture 2- Commerce 3- Elevage

4- Travailleur du public 5- Travailleur du privé 6- Autres à préciser :……………………………………………

D2- Quelle est votre activité principale parmi les activités citées plus haut?

1-Agriculture 2- Commerce 3- Elevage

4- Travailleur du public 5- Travailleur du privé 6- Autres à préciser

D3- Quelle est votre activité secondaire?

1- Aucune 2-Agriculture 3- Commerce 4- Elevage

5- Travailleur du public 6- Travailleur du privé 7- Autres à préciser

D4- Depuis combien de temps pratiquez-vous l'agriculture ?

1- Inférieur à 1 an 2- Compris entre 1 et 5 ans

3- Compris entre 6 et 10 ans 4- supérieur à 10 ans

D5- Comment financez-vous vos activités?

1- Fonds propres 2-Crédit 3- Aide familiale 4- Aide coopérative 5- Autre :…………………………………….

D6- Avez-vous accès au crédit agricole ?

1- Oui 2- Non si non aller a D8

D7- Avez-vous bénéficié d'un crédit agricole au moins une fois ces 5 dernières Années ?

1- Oui 2- Non

D8- Etes-vous membre d'une association agricole?

1- Oui 2- Non

D9- Recevez-vous des conseils et informations agricoles de la part des autorités compétentes ?

1- Oui 2- Non

E- INFORMATIONS CONCERNANT LE CHAMP ET LE SYSTEME DE PRODUCTION

E1- Combien de champs disposez-vous ?

E2- Quelle(s) est/sont la/les taille(s) de votre/vos champ(s) ?

1-Inferieur a 2 ha 2- Compris entre 2 et 5 ha

3- Compris entre 6 et 10 4- Supérieur à 10 ha

E3- Combien d'hectares avez-vous exploité cette année?

1-Inferieur a 2 ha 2- Compris entre 2 et 5 ha

3- Compris entre 6 et 10 4- Supérieur à 10 ha

E4- Comment avez-vous obtenu votre/vos terre(s) ?

1-Terre familiale 2- Achat 3- Location 4- Don

5- Prêt temporaire 4- Autre à préciser :……………………….

E5- Avez-vous un/des titre(s) foncier(s) pour votre/vos terres ?

1-Oui 2- Non Si oui aller à E7

E6- Sinon, le fait de n'avoir pas de titre foncier vous encourage-t-il à adopter des pratiques de gestion durable de votre/vos terre (s)?

1-Oui 2- Non

E7- Quelles sont les cultures que vous cultivez ?

....

E8- Quelles est la principale culture que vous cultivez ?...

E9- Quelle est la superficie que vous allouez à votre principale culture ?

……………………………………………………………………………………………

E10- Dans le/les même(s) champ(s), cultivez-vous plus d'une culture ?

1-Oui 2- Non Si non aller à E12

E11- Si oui, donner le nombre ……………………………………………………….

E12- Le champ est-il sur une pente ?

1-Oui 2- Non

E13- Avez-vous constaté une érosion des sols dans votre/vos champ(s) ?

1-Oui 2- Non Si non aller à E15

E14- Si oui, de quel type d'érosion s'agit-il ?

1-Erosion hydrique 2- Erosion éolienne 3-Autres

E15- Votre terre est-elle fertile ?

1-Oui 2- Non

E16- Utilisez-vous de fertilisants ?

1-Oui 2- Non Si non aller à E20

E17- Si oui, quel(s) type(s) de fertilisant(s) appliquez-vous dans votre/vos champ(s)

1-NPK 2- Ammoniac 3-Engrais organique 4- Fumier 5- Compost

E18- Donner la quantité de fertilisant appliquée par hectare dans votre/vos champ(s).

……………………………………………………………………………………………

E19- Combien coute le kg de type de fertilisant utilisé ?.......................................

E20- Pratiquez-vous la jachère ?

1-Oui 2- Non Si non aller à E22

E21- Quelle est la durée de la jachère?

1-Inferieur à 2ans 2- Compris entre 2 et 3 ans 3- Compris entre 4 et 5 ans 4- Superieur a 10 ans

E22- Irriguez- vous votre/vos culture(s) ?

1-Oui 2- Non Si non aller à E24

E23- Par quel moyen?

1-Puits 2-Marigot 3- Barrage 4- Autre a preciser :……………………………….

E24- Utilisez-vous des pesticides ?

1-Oui 2- Non Si non aller à E28

E25- Si oui, quel(s) types ?

1-Herbicides 2- Insecticides 3-Fongicide 4- Autre à préciser :……………………………………

E26- Donner la quantité de pesticide en kg/l utilisée dans votre/vos champ(s)……………………………………………………………………………………

E27- Indiquer le cout (Fcfa) par kg/l du pesticide utilisé………………………

E28- Quel(s) type(s) de semence utilisez-vous ?

1-Ordinaire 2-Ameliorée 3-Les deux 4- Autre à préciser :…………………………

E29- Donner la quantité de semence semée ?...

E30- Comment avez-vous obtenu ces semences?

1-Achat 2- Don 3-Crédit 4-Autre à préciser :………………………………………………………

E31- Pratiquez-vous le paillage dans votre champ(s)?

1-Oui 2- Non

E32- Avez-vous tracé des voies d'eaux dans votre/vos champ(s) ?

1-Oui 2- Non

E33- Pratiquez-vous la rotation des cultures dans votre/vos champ(s)?

1-Oui 2- Non

F- PRODUCTION AGRICOLE

F1- Quelle a été la production (en tonne) de votre champ à sa première utilisation…………

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

F2- A combien s'est élevé le montant total des dépenses cette année-là ?..............................

F3- Quelle a été la production(en tonne) de votre champ l'an dernier?..............................

F4- Sur les 10 dernières années, la production de votre/vos champ(s) a connu un changement?

1-Oui 2- Non Si non aller à F6

F5- Si oui, quel est le type de changement?

1- Augmentation 2- Diminution si 2 aller à F5

F6- Si augmentation, quelle est la raison?

1- Le climat est favorable 2-Mesure d'adaptation

3- Semence améliorée 4- Augmentation de la superficie

5- Utilisation de fertilisant 6- Utilisation de pesticide

7- La terre est fertile 8- Autre à préciser :……………………… (Après aller à F6)

F7- Si diminution, quelle est la raison?

1- Le climat n'est pas favorable 2- Dégradation des terres

3- Pas de mesure d'adaptation 4- Semence non adaptée

5- Non utilisation de fertilisants 6- Non utilisation de pesticides

7- Réduction de la superficie du champ 8- Autre à préciser :……………………………………………………

F8- Avez-vous vendu la récolte?

1-Oui 2- Non Si non aller à F10

F9- Si oui, où l'avez-vous vendu?

1- Marché 2- Bord champ 3- Autre à préciser

F10- Comment l'avez-vous vendu

1- Le kg 2-Le sac 3- Autre à préciser :……………………………………………………………..

F11- Quel est le montant total de la vente de la récolte (après aller à F11)………………………

F12- Si non, préciser l'usage ………………………………………………………

F13- Quel est le coût total de la production agricole?...

F14- Quel est votre revenu annuel?..

F15- Quelle est la distance du champ au lieu d'habitation?

1- Inférieur à 1 km 2- Compris entre 1 et 5 km

3- Compris entre 6 et 10 km 4- supérieur à 10 km

F16- Quelle est la distance du champ au marché?

1- Inférieur à 1 km 2- Compris entre 1 et 5 km

3- Compris entre 6 et 10 km 4- supérieur à 10 km

G- MAIN D'OEUVRE AGRICOLE

G1- Combien de personne dans votre famille travaille-t-elle avec vous?...........................

(si 0 aller a G5)

G2- Ces personnes sont-elles rémunérées?

1- Oui 2- Non Si non aller à G5

G3- Si oui, comment sont-elles rémunérées?

1- Heure 2- Jour 3- Semaine 4- Quinzaine 5- Mois

6- Trimestre 7- Semestre 8- An 9- Par recolte 10- Autre a preciser :………………………………….

G4- Combien coûte la main-d'œuvre ?...

G5- Combien de personne travaille- t-elle pour vous (sans membre de famille) ?..............

Si 0 aller a H1

G6- Ces personnes sont-elles rémunérées?

1- Oui 2- Non Si non aller à G10

G7- Si oui, comment sont-ils rémunérés?

1- Heure 2- Jour 3- Semaine 4- Quinzaine 5- Mois

6- Trimestre 7- Semestre 8- An 9- Par recolte 10- Autre a preciser :…………………………………………………..

G8- Combien coûte la main-d'oeuvre?..

G9- A combien s'élève le coût de la main-d'oeuvre totale?(apres aller a H1)....................................

G10- Si non, s'agit-il d'une aide: ☐

1- Aide amicale 2- Aide d'association 3- Autre à préciser :………………………………….

H- ELEVAGE

H1- Possédez-vous du bétail? ☐

1- Oui 2- Non Sinon aller à I1

H2- Si oui, quel genre de bétail avez-vous? ☐

1- Bœuf 2- Chèvre 3- Mouton 4- Poulet 5- Autre à préciser :…………………………

H3- Combien de tête avez-vous?..

H4- Comment nourrissez-vous votre bétail? ☐

1- Résidu de culture 2- Matière première 3- Mélange des 2 premiers Si 4 ou 5 aller à H8

4- Broutage libre 5- Broutage guidé 6- Autre à préciser :……………………………………………

H5- Achetez-vous ces aliments? ☐

1- Oui 2- Non si non aller à H7

H6- Si oui, combien coûte ces aliments par mois?..

H7- Combien de sac d'aliment de bétail utilisez-vous dans votre ferme ?............................

H8- Quel est le coût total de production animale?..

I- PERCEPTION DU CHANGEMENT CLIMATIQUE ET DE LA DEGRADATION DES TERRES

I1- Au cours des 10 dernières années, avez-vous constaté un changement du climat? 1- Oui 2- Non Si non aller à I3 ☐

I2- Si oui, quel changement avez-vous observé? (cocher les choix possibles) ☐

1-Augmentation de la température 2- Diminution de la température

3- Augmentation de la pluviométrie 4- Diminution de la pluviométrie

I3- Avez-vous entendu parler du changement climatique? ☐

1- Oui 2- Non Si non aller à I12

I4- Si oui, que savez-vous du changement climatique?...

……………………………………………………………………………………………

I5- Quelle est votre perception à propos du changement climatique? ☐

1- Réelle 2- Pas réelle 3- Aucune idée 4- Autre à préciser :…………………… Si autre que 1 aller à I12

I6- Qu'est ce qui peut causer le changement climatique? ☐

1- Activité agricole 2- Activité industrielle 3- Déforestation

4- Urbanisation 5- Cause naturelle 6- Autre à préciser :……………………………………………………

I7- Adoptez-vous des pratiques d'adaptation au changement climatiques ? ☐

1- Oui 2- Non Si non aller à I12

I8- Si oui, Enumérer ces pratiques: ☐

1- Semence améliorée 2- Utilisation de fertilisants 3-Diversification des cultures

4-Irrigation 5-Culture associée

I9- Adoptez-vous des pratiques d'adaptation simultanées dans votre/vos champ(s)? ☐

1- Oui 2- Non Si non aller à I12

I10- Si oui, quelles sont ces pratiques ? (Cocher au moins deux choix) ☐

1-Semence améliorée

2-Diversification de culture

3-Fertilisants

4-Irrigation

5-Culture associée

6- Autre à préciser :…………………………………

I11- Ces pratiques ont-elles été bénéfiques? ☐

1- Oui 2- Non

I12- Avez-vous entendu parler de la dégradation des terres? ☐

1- Oui 2- Non Si non aller à I21

I13- Si oui, que savez-vous de la dégradation des terres?..

…………………………………………………………………………………………………

I14- Quelle est votre perception à propos de la dégradation des terres? ☐

1- Réelle 2- Pas réelle 3- Aucune idée 4- Autre à préciser :………………………..Si autre que 1 aller à I21

I15- Qu'est ce qui peut causer la dégradation des terres? ☐

1- Activité agricole 2- Activité industrielle 3- Déforestation

4- Urbanisation 5- Cause naturelle 6- Autre à préciser :……………………………………………………

I16- Adoptez-vous des pratiques de gestion durable des terres? ☐

1- Oui 2- Non Si non aller à I21

I17- Si oui, Enumérer ces pratiques : ☐

1-Agroforesterie 2-Utilisation de fertilisants 3-Rotation de culture

4-Culture associée 5-Jachere 6-Irrigation 7- Paillage 8-Terrassement

I18- Adoptez-vous des pratiques ou techniques simultanées de gestion durable dans votre/vos champ(s)?

1- Oui 2- Non Si non aller à I21

I19- Si oui, quelles sont ces pratiques ou techniques? (Cocher au moins deux choix)

1-Agroforesterie

2-Utilisation de fertilisants

3-Rotation de culture

4-Culture associée

5-Jachere

6-Irrigation

7-Paillage

8-Terrassement

9- Autre a préciser :……………………………

I20- Ces pratiques ont-elles été bénéfiques?

1- Oui 2- Non

I21- Quel est le type de sol dans votre/vos champs?...