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DEFORESTATION IN CAMEROON,

CAUSES AND EFFECTS ON CEREAL

YIELDS, POPULATION VULNERABILITY AND RESPONSE

THROUGH REFORESTATION AND OTHER POLICIES

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BY
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UNIVERSITÉ DU QUÉBEC À MONTRÉAL

DÉBOISEMENT AU CAMEROUN, LES CAUSES ET LES EFFETS SUR
LES RENDEMENTS CÉRÉALIERS, LA VULNÉRABILITÉ DES POPULATIONS
ET RÉPONSE À TRAVERS LE REBOISEMENT ET AUTRES POLITIQUES.

THÈSE

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PAR

EPULE TERENCE EPULE

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PREFACE

This doctoral thesis is comprised of eight chapters. **Chapters one** and **eight** are the general introduction and general conclusion. Chapters two, three, four, five, six and seven are the six main chapters that present and discuss the causes of forest loss (**chapter two**), the interactions between causal variables (**chapter three**), the dilemma of the effects of deforestation and climate change on cereal yields (**chapter four**), the vulnerability of the population to food shortages with respect to income levels and gender (**chapter five**), the reasons why reforestation or tree planting has succeeded in some areas and why it has failed in others (**chapter six**) and the policies that can assist in overcoming deforestation based on an analysis of agents and drivers (**chapter seven**). The publications that make up chapters two, three, four, five, six and seven are as follows:

- Chapter II: Epule, T.E.,** Peng, C., Lepage, L., Chen, Z. (2011) Forest loss triggers in Cameroon: A quantitative assessment using multiple linear regression approach. *Journal of Geography and Geology*, 3(1), 30-40. Doi: 10.5539/jgg.v3nlp30.
- Chapter III: Epule, T.E.,** Peng, C., Lepage, L., Chen, Z., Balgah, S.N. (2012) The environmental quadruple: Forest area, rainfall, CO₂ emissions and arable production interactions in Cameroon. *British Journal of Environment and Climate Change*, 2(1), 12-27.
- Chapter IV: Epule, T.E.,** Peng, C., Lepage, L., Chen, Z. (2011) The Rainfall and deforestation dilemmas for cereal production in the Sudano-Sahel of Cameroon. *Journal of Agricultural Science*, 4 (2), 1-10. Doi:10.5539/jas.v4n2p1.

Chapter V: Epule, T.E., Peng, C., Lepage, L., Chen, Z. (2012) Poverty and gender oriented vulnerabilities to food and water scarcity in Touroua, Cameroon. *Journal of Human Ecology*, 38(2), 81-90.

Chapter VI: Epule, T.E., Peng, C., Lepage, L., Chen, Z. (2013) Enabling conditions for successful greening of public spaces: The case of Touroua, Cameroon Based on Perceptions. *Small Scale Forestry*, Doi: 10.1007/s11842-013-9246-2.

Chapter VII: Epule, T.E., Peng, C., Lepage, L., Chen, Z. (2014) Policies options towards deforestation reduction in Cameroon: an analysis based on a systematic approach. *Land Use Policy*, 36, 405-415. Doi:10.1016/j.landusepol.2013.09.004.

Appendix A is a paper from my comprehensive exam. It deals with the causes, effects and challenges of droughts in the Sahel. **Appendix B** is another publication that looks at the food security issues between Africa and Asia. **Appendix C** is a review paper on methane emissions from paddy rice fields and mitigation strategies; as well as other papers not included in the appendix for reasons of space but their full citations have been mentioned below under others.

Appendix A: Epule, T.E., Peng, C., Lepage, L., Chen, Z. (2014) The causes, effects and challenges of Sahelian droughts: a critical review. *Regional Environmental Change*, 14(2), 145-156. Doi: 10.1007/s10113-0473-z.

Appendix B: Epule, T.E., Peng, C., Lepage, L., Nghu, B.S., Mafany, N.M. (2012) Can the African food supply model learns from the Asian food supply model? Quantification with statistical methods. *Environment, Development and Sustainability*, 14(4), 593-610. Doi: 10.1007/s10668-012-9341-0.

- Appendix C: Epule, T.E., Peng, C., Mafany, N.M. (2011)** Methane emissions from paddy rice fields: Strategies towards achieving a win-win sustainability scenario between rice production and methane emission reduction. *Journal of Sustainable Development*, 4(6), 188-196. Doi:10.5539/jsd.v4n6p188.
- Other A: Epule, T.E., Peng, C., Wase, M.M., Mafany, N.M. (2011)** Well water quality and the occurrence of diarrheal disease cholera in four neighbourhoods of the city of Douala Cameroon. *Global Journal of Health Science*, 3(2), 75-83. Doi: 10.5539/gjhs.v3n2p75.
- Other B: Epule, T.E., Peng, C., Wase, M.M., Peng, C., Nguh, B.S., Nyangero, J., Lakati, A., Mafany, N.M. (2013)** Utilization of voluntary counselling and testing (VCT) services in Kiogoro Division, Kisii Central District, Kenya. *Global Journal of Health Science*, 5(1), 35-43. Doi.org/10.5539/gjhs.v5n1p35.
- Other C: Epule, T.E., Peng, C., Lepage, L., Chen, Z., Nguh, B.S. (2013)** Implications of fitting a regression and Pearson correlation models in the relationship between food production, production of wood products, CO₂ emissions and climate change: An analysis of time series data. *Research Journal of Environmental Science*, Doi:10.3923/rjes.2013.1.14.
- Other D: Epule, T.E., Peng, C., Lepage, L. (2014)** Environmental refugees in sub-Saharan Africa: a review of perspectives on the trends, causes, challenges and way forward. *GeoJournal*, Doi: 10.1007/s10708-014-9528-z.

All the publications from chapter two to seven and appendix A, B and C are original contributions to my PhD research. I developed the hypothesis, research questions and identified appropriate methods. I had comments and suggestions from my supervisor and supervisory committee members.

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RÉSUMÉ

La perte de forêt pourrait être attribuée à plusieurs variables qui pourraient être naturelles ou humaines. Cette étude vise à vérifier quantitativement les réelles causes du déboisement à une échelle nationale au Cameroun parmi les variables indépendantes suivantes (bétail, production de nourriture, bois de chauffage, terres agricoles permanentes, précipitations, population et produits forestiers). Cette étude examine également les interactions entre les variables telles que la zone forestière, les précipitations, les émissions de CO₂ et la production de nourriture à une échelle nationale. En outre, une analyse des effets relatifs du déboisement et des changements climatiques sur les rendements de céréales à une échelle d'étude de cas est effectuée. Ceci est suivi d'une enquête sur l'ampleur de la vulnérabilité des personnes selon leur genre et revenu à une échelle d'étude de cas. En outre, cette étude examine les raisons du succès et de l'échec dans deux projets de reboisement et examine finalement les politiques qui pourraient être adoptées pour réduire le déboisement au Cameroun.

Pour vérifier les causes de la perte des forêts et les interactions entre les variables, différentes données sur les diverses variables ont été obtenues au FAOSTAT, World Resource Institute, UNEP, Université d'Oxford et Banque Mondiale. Ceci était des données de séries chronologiques entre 1961-2000. 200 questionnaires ont été administrés pour vérifier les perceptions des céréaliers sur les contributions relatives des précipitations et du déboisement sur les rendements en baisse des céréales pour vérifier les raisons du succès et de l'échec des projets de reboisement et pour évaluer la vulnérabilité des populations selon leur genre et revenu. Des données de séries chronologiques sur la production de céréales réelle et projetée entre 1975-2005 ont été obtenues au Bureau de céréales à Garoua. Des données de NDVI et des précipitations ont été obtenues à l'Advanced very High Resolution Radiometer (AVHRR), United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). Des données de NDVI ont été corrélées avec des précipitations. Les données sur les causes de la perte des forêts et les interactions entre les variables ont été analysées avec R programming et SPSS en utilisant des régressions linéaires, des complots de séries chronologiques, des matrices de corrélation et des coefficients de détermination. Les 200 questionnaires ont été analysés dans SPSS afin de calculer des pourcentages, fréquences et corrélations de Pearson. Les données de séries chronologiques sur la production de céréales ont été analysées en soustrayant la production réelle de la production projetée; la méthode de *three period moving averages* a également été utilisée sur ces données. Les données sur les tendances des précipitations et des forêts pour le Sahel ont été analysées. Pour analyser les politiques contre le déboisement, une analyse systématique des causes et agents a été appliquée.

Cette étude a constaté que la population et la production de nourriture sont les causes principales de la perte des forêts. En outre, pendant que la quantité de forêt réduit, les émissions de CO₂ augmentent. D'autre part, pendant que les forêts et les précipitations diminuent, la production de nourriture réduit également. La baisse de quantité de forêts est davantage liée aux baisses de production de nourriture qu'aux précipitations. De la même manière, la plupart des répondants dans la zone d'étude pensent que le déboisement est davantage responsable des baisses de rendement de cereals que les précipitations. En termes de vulnérabilité, les femmes et les pauvres sont les plus affectés par les baisses de nourriture parce que les pauvres n'ont pas assez de revenu pour acheter de la nourriture dans les périodes de pénurie, alors que les femmes dans cette région sont naturellement associées à la production d'aliments. Des politiques qui aideront à réduire le déboisement devraient être adaptées. Incluant l'intensification de l'agriculture, entre autres. Il existe un lien direct entre le succès de la plantation et la participation active des parties prenantes.

Mots-clefs: déboisement, causes et les effets, rendements céréaliers, la vulnérabilité des populations, le reboisement et autres politiques, Cameroun

ABSTRACT

Forest area loss could be attributed to several variables which could either be natural or human. The overall objective of this study is to verify quantitatively the actual causes of deforestation at a national scale in Cameroon from among the following independent variables (cattle stock, arable production, fuel wood, arable production and permanent crop land, rainfall, population and trade in forests products/logging) and to propose policies that can be used to subvert deforestation. Specifically, it will examine the influence of forest area change on CO₂ emissions and cereal production. This will be followed by a survey of the extent of vulnerability of respondents to food and water scarcities with respect to gender and income levels at a case study scale. In addition, this study surveys the reasons for success and failure in two reforestation projects.

To verify the causes of forest area loss and the effects on CO₂ emissions, data on the various variables was collected from FAOSTAT, World Resource Institute, UNEP/Oxford University data bases and the World Bank. Much of this was time series data spanning 1961-2000. Also, 200 questionnaires were administered to verify the perceptions of respondents on the relative contributions of climate change and deforestation on declining cereal yields; NDVI and rainfall data were also collected from the Advanced Very High Resolution Radiometer (AVHRR), United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). To verify the reasons for success and failure in two reforestation projects and to evaluate the vulnerability of the respondents along gender and income level lines, 200 questionnaires were administered and focus group discussions held. To determine cereal yield shortages, time series data on actual and projected cereal production spanning 1975-2005 were obtained from the cereal office in Garoua. Data on rainfall and forest correlations for the entire Sahel was also used for downscaling.

The data on the causes of forest area loss and the interactions between variables were analyzed in both the R programming interface and SPSS using multiple linear regressions, time series plots, correlation matrices and coefficient of determination. The 200 questionnaires were analyzed in the SPSS in which percentages, frequencies, chi-square and Pearson correlations were calculated. The time series data on cereal production was analyzed using a simple actual production minus projected production as well as the three period moving averages. NDVI and rainfall anomalies data for the three Northern regions of Cameroon were charted and correlated. The data on rainfall and forest for the Sahel were downscaled to the Sahel of Cameroon and the relationship observed. To analyze the policies against deforestation, a systematic analysis of drivers and agents was applied.

This study has found that population and arable production are the key causes of forest area loss. Also, as forest area reduces, CO₂ emissions increase. On the other hand, as forest area and rainfall reduce, arable production also reduces but forest area decline is more responsible for changes in arable production than rainfall. This supports the hypothesis that human oriented deforestation has a more dominant role than rainfall. In the same way, most of the respondents in the study area think deforestation is more responsible for declines in cereal yields since rising rainfall and greening have a very high correlation as seen in large scale Sahelian downscaled

data and a very weak correlation as seen in specific data from the study area. The implication is that due to wide scale deforestation, much of the moisture is not available for agriculture. In the area of vulnerability, the low income groups and females are more vulnerable to food declines because the poor do not have enough income to purchase food in periods of shortages while women in this region are naturally associated with the provision of food for their households. The main reasons for success and failure in tree planting are the participation of stakeholders and the absence of participation of stakeholders respectively. The key policies that will help reduce deforestation should be geared towards controlling population and arable production intensification. Also, since the reduction of deforestation will reduce the contribution of forestry to employment and GDP, collaborations, setting of quotas, licensing, monitoring, specification of tasks, enforcement, adherence, and frameworks like REDD+ would be an advantage. The main weaknesses of this study are: the use of 220 Kha for annual forest area loss which causes forest area to decline in a linear fashion, the lack of data for variables such as fire and insects which have a great role to play in forest area dynamics of the region, the use of income levels as the main indicator of poverty whereas there are many more and the inability to reflect vulnerability from an age perspective, the problem of multi-collinearity among independent variables subjecting the models to further optimization.

Keywords: deforestation, causes and effects, cereal yields, population vulnerability, reforestation and other policies, Cameroon

CHAPTER I

GENERAL INTRODUCTION

1.1. BACKGROUND

1.1.1. Tropical forest and Grassland loss

Tropical deforestation has several repercussions that result in ecological instability and long term social and economic development problems (Mertens and Lambin, 1997). Tropical forests are often seen as systems that depict many aspects of the interactions between environmental, ecological, economic and socio-cultural aspects of ecosystems interaction (Armenteras *et al.*, 2010). There is an increasing argument that tropical deforestation is increasingly contributing to the reduction of global bio-carbon stock, reduced agricultural output, adversely affecting discharge in rivers to name a few (Armenteras *et al.*, 2010). Global forests store approximately 45% of terrestrial carbon (Bonan, 2008). When global biomes are considered, tropical forests are said to store about 471 Pg C (petagrams of carbon) (55%) while the temperate and boreal forests store 119 Pg C (14%) and 272 Pg C (32%) respectively (Pan *et al.*, 2011).

Tropical forests are under pressure from global change processes such as population growth, slash and burn fires, wildfires, fuel wood usage, agricultural expansion, economic logging factor, rainfall variations, temperature fluctuations, acid rain, insect outbreaks, frequent droughts and some human policy oriented issues (Mertens and Lambin, 1997; Agvei, 1997; Sivakumar, 2007; Bond-Lamberty *et al.*, 2007; Kur *et al.*, 2008; Allen *et al.*, 2010; Muller *et al.*, 2013). In spite of this wealth of knowledge, the spatio-temporal variations that are inherent in different African

countries make it difficult for us to reliably assert which factors are dominant in the different countries. This equally makes policy and intervention a daunting task and resultant reforestation policies have been too simplistic, not based on the realities of the given context, not well understood and handled (Clement and Amezaga, 2008; Armenteras *et al.*, 2010; Mani and Viju, 2008).

The central question that arises now is why deforestation or forest area loss is very important in the tropics in general and Cameroon in particular? Firstly, the drivers of deforestation may be numerous and some may include: population growth, slash and burn cultivation, wildfires, fuel wood gathering, agricultural expansion, logging, rainfall, temperature, acid rains, insect outbreaks, droughts and policy loopholes (Salam and Noguchi, 1998; Allan and Barnes, 1985; Fischer and Vasseur, 2000; Carr *et al.*, 2005). As many as there maybe drivers of deforestation, data is often not available, existing studies are speculative and not empirically grounded and there is a lot of spatial variations as one moves across countries, making the application of examples from other countries a daunting task (Agarwal *et al.*, 2005; Armenteras *et al.*, 2010); that is why, this study will empirically verify the causes of deforestation in Cameroon.

Secondly, exploring the linkages between deforestation and CO₂ emissions is vital as observations of wide scale deforestation may mean increase atmospheric CO₂ (Figure 1.1.). It has been argued that tropical forests are very important as they are host to larger biocarbon stocks (55%) when compared to the temperate forests (14%) and boreal forests (31%) (Binan, 2008; Pan *et al.*, 2011). Unfortunately, in Cameroon this relationship has not been examined. Furthermore, increase deforestation is likely to cause droughts, decrease rainfall and ultimately decrease food production (Figure 1.1.) (Jianjung *et al.*, 2010). This linkage between deforestation and food production has not been explored in Cameroon. In Cameroon and most of the tropics, about 70-80% of the population is made of farmers or people dependent on primary activities. Therefore, if deforestation is impacting agriculture in anyway, it is also vital to verify

the specific groups that are affected along income level and gender lines (Challinor *et al.*, 2007; Misselhorn, 2004; IPCC, 2007).

Additionally, with Cameroon losing about 220 Kha of forest annually (FAO, 2010); it is obvious that urgent measures to curb deforestation are needed. Therefore, in addition to basing such country specific policies on the drivers of deforestation, it is also necessary to evaluate population perceptions of the socio-economic and technical reasons why reforestation projects either fail or succeed (Le *et al.*, 2012). The emphasis on these categories of drivers is based on an argument that the socio-economic and technical drivers of reforestation success are more important than the biophysical drivers (climate, geology, edaphic) (Lamb, 1988; Walters, 1997; Crk *et al.*, 2009; Le *et al.*, 2012). This means the issues taken into consideration in the design and execution of the projects are often more important than the environmental site conditions. Even when the site conditions such as the rainfall, soils and geology are not suitable, efficient socio-economic and technical arrangements can enhance success. A visual representation of the fit and linkages between these facets in this thesis is found on figure 1.2.

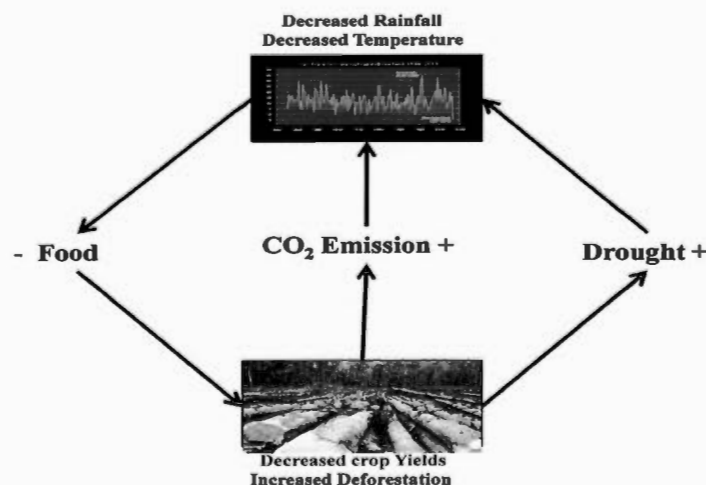


Figure 1.1. The linkages between deforestation and CO₂ emissions and food production

1.1.2. Problem Statement

Forest area loss has varying effects in many parts of the world. While it has led to increasing agricultural productivity in Europe and Asia, agricultural productivity has instead declined in Africa in general and Cameroon in particular in the midst of increasing farm sizes (Rounsevell *et al.*, 2005; Zhao *et al.*, 2006; Food and Agricultural Organization, FAO, 2009). In addition, between 2000 and 2010, the net loss of forest in Africa stemming from deforestation was 3.4 million hectares (Mha) per year. Comparatively, this value is better than found in South America with a net loss of 4.0 Mha per year during the same period. However, Africa still lags behind in attempts at reducing forest loss when compared to Europe and Asia which had net gains of 700 thousand (Kha) per year and 2.2 Mha per year respectively between 2000 and 2010 due mainly to large scale reforestation successes (FAO, 2010).

Cameroon has about 465400 km² in surface area. In 2005 its forest area was estimated at 26 Mha while in 2000 it was estimated at 28 Mha (FAO, 2009; Harris *et al.*, 2012). Other estimates assume that in 2010 the total forest area was about 19 Mha (FAO, 2010). From this, about 42% of the total forests are made of tropical rainforest (FAO, 2009). In Cameroon, about 220 Kha of forests were lost yearly during the decade 1990-2000 with deforestation rates between 0.6-1.0% per annum (FAO, 2010). Some other authors argue that the annual forest area loss in Cameroon between 2000 and 2005 was about 54 Kha (Harris *et al.*, 2012). Most studies that have treated deforestation in Cameroon do not have a clear cut analysis of the exact causes (Agarwal *et al.*, 2005). Between 2000 and 2005 the forest carbon density was 142 megagrams of carbon (Mg C) per ha while carbon emissions were 7 tertagrams of carbon (Tg C) per year (Harris *et al.*, 2012). Currently, about 2,696 million metric tons of carbon is stored in living biomass in Cameroon (FAO, 2010).

It is not clear whether population increase is at the centre of the current problems of deforestation, food insecurity and water resource quantity and quality degradation (Bala *et al.*, 2009). In Africa, elements of land use change such as population and

deforestation have had repercussions on the long term output of agricultural produce, water quality and quantity and green house gas emission fluxes. This means that as populations grow and the need for more farmland is created, more and more hectares of forests are lost while catchment water quality and quantity are compromised (Lambin *et al.*, 2000; FAO, 2009; Zhao *et al.*, 2006; Shuying and Xi, 2006). Some authors argue that the primary pressure behind this wide scale land cover transformation is population growth and demand for agricultural land. These studies have not carried out any quantification to enhance certainty (Jianjung *et al.*, 2010). Since the end of the period for which the data in this study is based (1961-2000), African population growth rate as a continent stood at an average of 2.4 percent. This varied from region to region with rates of 2.0 and 1.6 percent respectively in northern and southern Africa. In western and central Africa, the rates of population growth were 2.5 and 2.7 percent respectively (UNFPA, 1999). Agricultural expansion for the purpose of feeding an increasing human and animal population led to deforestation (Stephenne and Lambin, 2001). The population of Cameroon in the year 2000 was estimated at about 15.4 million people with a growth rate of 2.47%. In 2012, Cameroon's population was about 20.03 million people with an annual growth rate of 2.08% (Mundex Dataset, 2012). This invariably exerts a lot of pressure on forest resources. However, the exact causes of deforestation have not been quantitatively verified. Because of this loophole, reforestation projects have equally been faced with varied levels of success.

The eminent stress imposed by deforestation in Cameroon will keep rising in the 21st century due mainly to a desire to feed "more mouths" with a resultant cultivation of more land area (Lambin *et al.*, 2000). The latter view is supported by an argument that food declines in Cameroon will still be a problem in both the short and long term especially in the drier northern regions with poverty and population growth being key elements in food security (Misselhorn, 2004; Wardell *et al.*, 2003; Molua and Lambi, 2006).

As deforestation increases, it causes a parallel increase in atmospheric carbon (FAO, 2009). About 90 % of the population use fuel wood which contributes about 52% of the entire African energy budget. In Cameroon, more than 2000 million metric tons of carbon is stored in living vegetation (FAO, 2010). Land clearance by farmers for agricultural and other reasons is now judged to produce (about 462 metric tons of CO₂ lost per hectare) as much effects as fuel wood (Agvei, 1997; FAO, 2010).

On the other hand, existing studies of the causes of forest loss in Cameroon have been described as too simplistic, generalized or not focused enough (Agarwal *et al.*, 2005). As such, in the absence of a clear picture of the causes, reforestation schemes have had minimal success in many parts of the world (Agarwal *et al.*, 2005). The dynamics responsible for this situation are still unknown because as seen in the literature the causes of deforestation in the Sahel have not been clearly analyzed. The question, why are the observed factors the drivers of deforestation and reforestation in one situation and not another has not been answered (Clement and Amezaga, 2008). As such, most analysis tends to be based on more generalized reports of the causes of deforestation with little emphasis on the level of success of reforestation projects.

The precursors to the effects of deforestation are certain income groups and gender (IPCC, 2007; Challinor *et al.*, 2007; Misselhorn, 2004; IPCC, 2007; Skeggs, 1997; Confalonieri *et al.*, 2010). Most studies in this area of vulnerability have dwelled mostly on vulnerability to climate change and they have simply mentioned that certain segments of the population are more vulnerable (IPCC, 2007). No detailed studies have been thus carried out that have been able to quantify the exact level of vulnerability for some communities in Cameroon with respect to poverty and gender, this study will also fill this gap.

As such, this study has as general objectives the examination of the causes of forest area loss in Cameroon and proposes specific policies that can be used to solve the problem. In addition, an analysis of the effects of forest area loss on CO₂ emissions

and cereal production will be examined. This will be followed by an examination of population perceptions on vulnerability to food and water scarcity caused by deforestation along gender and income level lines. The reasons for success and failure in two tree planting based on population perceptions will also be examined.

1.2. GENERAL OBJECTIVES AND HYPOTHESIS

This study has as main goals to quantitatively verify the main causes of deforestation in Cameroon and to propose policies that can be used to subvert the crisis. To achieve these overall objectives, this study will: quantify the causes of deforestation, analyse the interactions between deforestation on the one hand and CO₂ emissions and agriculture on the other hand, verify population perceptions on the extent of vulnerability to the effects of deforestation (food and water scarcity) on different income groups and gender, verify population perceptions on the reasons for varied levels of success in tree planting projects and effective policies to counter the surge of deforestation.

The hypotheses that will guide this study are as follows: (1) population growth and arable production have a stronger effect on forest area loss than other variables; (2) forest area loss or deforestation has an inverse relationship with CO₂ emissions; (3) forest area loss is more responsible for the observed declines in cereal production than rainfall; (4) females and the low income households are more vulnerable to food deficits; (5) stakeholder inclusion and participation in reforestation project design and implementation is vital in the success of any reforestation project; (6) policies to curb deforestation should be based on the specific drivers of deforestation in a given country given the great spatial variations that exist along environmental, social and political lines.

1.3. SPECIFIC OBJECTIVES AND THESIS STRUCTURE

This thesis is made of eight chapters. Chapters one and eight are the general introduction and general conclusions respectively. Chapter two, three, four, five, six and seven are the key related publications (Figure 1.2.).

The specific objectives of this thesis are as follows:

- (1) Chapter II: The objectives of this chapter are to examine and quantify the causes of deforestation in Cameroon through statistical models determined by a multiple linear regression approach which will enable a classification of the most important causal factors. The key variables that will be analyzed in the linear regression equation will be: forest area, cattle stock, arable output per capita, arable and permanent crop land, rainfall, trade in forest products, population and fuel wood.
- (2) Chapter III: This chapter seeks to verify how forest area dynamics influence CO₂ emissions, rainfall, and arable production and how rainfall affects arable production and CO₂ emissions. This approach is vital because a holistic approach of most environmental variables can be better explained from a systemic approach rather than from an isolation of variables.
- (3) Chapter IV: This chapter seeks to verify how forest area dynamics influence cereal deficits in comparison to the influence of general Sahel Cameroon rainfall.
- (4) Chapter V: This chapter aims at verifying through population perceptions the extent to which, poverty levels (income levels) and gender are differentially susceptible to famine (food shortages) and water scarcity caused by deforestation in Touroua, Cameroon.
- (5) Chapter VI: Investigates the perceptions of the respondents with respect to their understanding of what success and failure in tree planting is all about, their judgment of whether the tree planting projects were successful or failure and their perceptions of the reasons for such success or failure.
- (6) Chapter VII: This chapter aims at using a systematic approach (Muller *et al.*, 2013) to come out with policies that can help reduce deforestation in Cameroon. To this end, it becomes necessary to carry out an in-depth analysis of the drivers, agents and land use types.

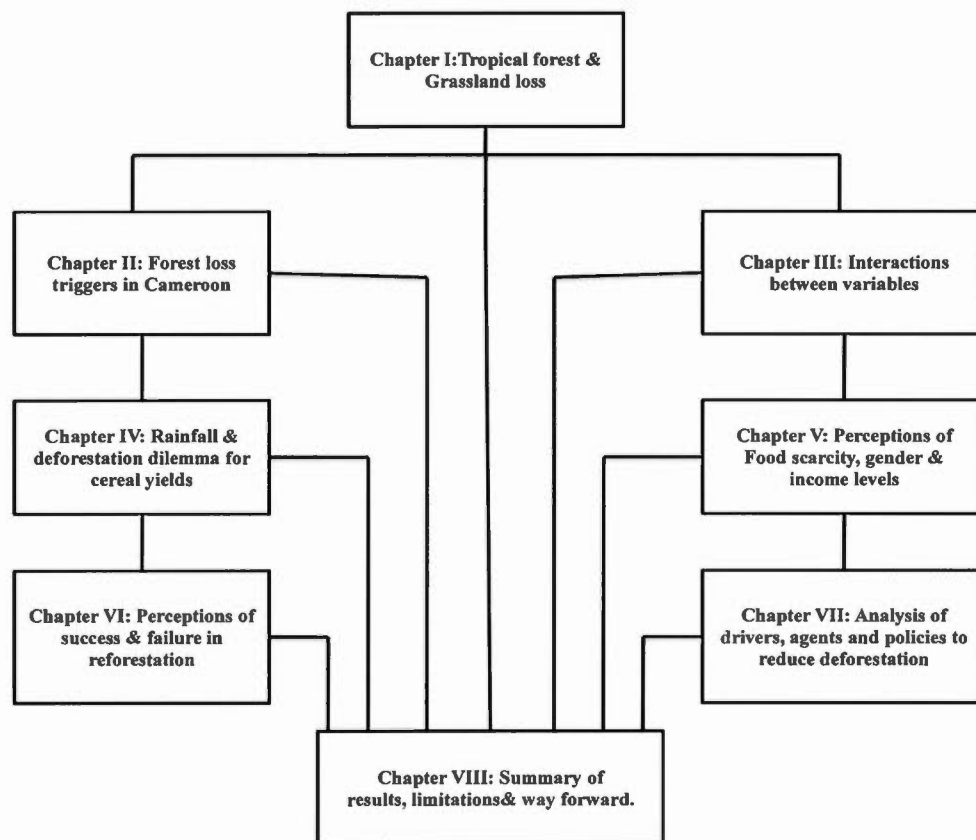


Figure 1.2. Thesis structure

1.4. THE STUDY AREA

Cameroon is located between latitude 2°N and 13°N of the equator and longitude 8°E and 15°E of the Greenwich meridian. It has a total surface area of 475,400 km² and a population of over 20 million people. Agriculture employs about 70-80% of the country's population. Forest extraction related activities account for about 10% of the GDP and provide about 45000-70000 jobs. Climatically, the country has an equatorial climate in the south with rainfall of between 1500-2000 mm annually and temperatures of about 25°C. In the north, there is a tropical humid climate around areas like Garoua and Maroua with rainfall amounts around 900 mm while as one

moves further north of Maroua there is a Sudano-Sahelian climate with rainfall as low as 400 mm and temperatures of 28°C in Kousseri. The generalized trend is that as we transition from the south to the north there is a decline in rainfall. In the same way, there is a change in the vegetation type from tropical rainforest in the south to Guinea, Sudan and Sahel Savanna in the northern regions.

This study is carried out at two scales. We have national scale analyses of the causes of forest area loss (chapter two), the interactions between the causal variables (chapter three) and an analysis of the agents and policies that can reduce deforestation (chapter seven). The rest of the chapters are treated at case study scales and principally in the drier north of the country. Chapter four is based on the role of rainfall and deforestation in accounting for the levels of cereal yields in the Sahel of Cameroon. Chapters five and six are based on population vulnerability along gender and income level lines and the reasons for success and failure in reforestation projects in Touroua (Figure 1.3.).

This thesis is based on a collection of six published peer review papers. As such, there is some overlap in the texts between the introduction, the body, the general conclusion and appendices.

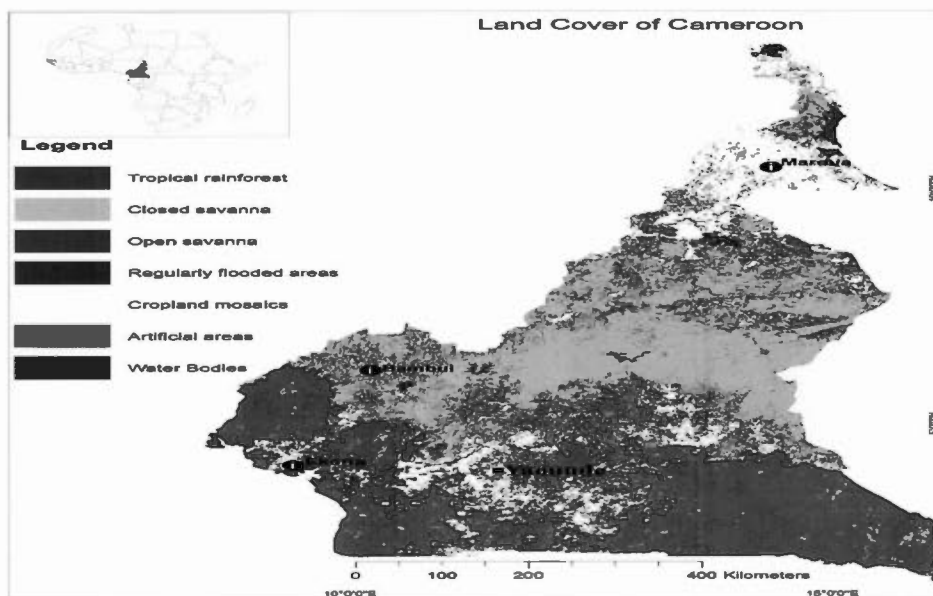


Figure 1.3. The study area: Forest Regions in Cameroon

Source: Pulled and modified from Yengoh and Ardo, (2013); Civil Society engagement with ecological economics (<http://www.ccecec.net/the-project/>).

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CHAPTER II

FOREST LOSS TRIGGERS IN CAMEROON: A QUANTITATIVE ASSESSMENT USING MULTIPLE LINEAR REGRESSION APPROACH

This chapter has been published as:

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2.1. RÉSUMÉ

Les déclencheurs de la perte des forêts au Cameroun n'ont pas été correctement compris. Les mesures employées pour limiter la perte des forêts ont été simplistes, généralisées et sans la connaissance définie du rôle spécifique de différents facteurs potentiels. Cette étude vise à étudier l'hypothèse que la croissance démographique est la cause principale de la perte des forêts. Cette étude identifiera les facteurs qui sont les plus importants dans l'équation causale. Le logiciel de programmation ouvert R a été employé pour produire des modèles multiples linéaires. La corrélation entre la variable dépendante (forêts) et les variables indépendantes a été établie par une matrice de corrélation et la force des modèles examinés par une analyse de puissance. La croissance démographique est la cause la plus dominante du déboisement au Cameroun, tandis que la production agricole est la deuxième.

2.2. ABSTRACT

The triggers of forest area loss in Cameroon have not been properly understood. The measures used to curb forest area loss have been simplistic, generalized with no clear cut knowledge of the specific role of different potential factors. This study aims at investigating the hypothesis that population growth is the main cause of loss in forest area. This study will be able to identify what factors are of more significance in the causal equation. The open R programming software has been used to produce multiple linear regression models. The correlation between the dependent variable and the independent variables was established by a correlation matrix and the strength of the models tested by power analysis. The results supports the hypothesis that population growth is the most dominant cause of deforestation in Cameroon while arable production and permanent crop land and arable production per capita index are second and third respectively. The main weaknesses of these models are that some of the variables suffer from multi-collinearity while the models assume a constant yearly rate of decline in forest area of 220 Kha/year. Also, other variables that affect forest area dynamics such as fires, soils, insects and acid rains are not factored into these models for reasons of data availability.

Keywords: forest loss, population, arable and permanent crop land, arable production per capita index, multiple linear regressions

2.3. INTRODUCTION

Tropical forests are widely known as key terrestrial ecosystems for our life support system. They affect environmental, economic and socio-cultural components of human life (Armenteras *et al.*, 2010). Most of the models of forest loss that have been developed in recent years include a combination of economic, demographic, institutional, and climatic variables whose share strength in net forest loss tends to vary spatially and temporally (Armenteras *et al.*, 2010). To adequately understand the role of forest loss in the earth's future, it is necessary to not only measure when and where the changes have occurred but also have a good understanding of the causal factors that are specific to different countries (Lambin and Ehrlich, 1997). The development of empirical models on the causes of deforestation in a given country is of importance because it enhances understanding of the specific situations in given countries and also makes policies towards mitigation more effective (Mertens and Lambin, 1997).

The causes of deforestation in sub-Saharan Africa *inter alia* include population growth, slash and burn fires, fuel wood usage, agricultural expansion, cattle rearing and the economic logging factor *inter alia* (Mertens and Lambin, 1997; Agve, 1997). In spite of this wealth of knowledge on the causes of forest area change in sub-Saharan Africa, the spatio-temporal variations inherent in different countries make it difficult to reliably assert which factors are dominant in the different countries. The repercussions are that policies and interventions to curb deforestation remain daunting since measures to curb land cover change in the region are currently highly simplistic, generalized and without emphasis on spatial variations in different countries (Clement and Amezaga, 2008; Armenteras *et al.*, 2010).

Conventional analysis on the causes of forest area loss in sub-Saharan Africa has been described as either too simplistic or generalized since spatial variations have not been considered (Agarwal *et al.*, 2005). The question, why are the observed factors

the drivers of deforestation and reforestation in one situation and not the other has not been clearly answered (Clement and Amezaga, 2008).

Cameroon has a total area of 475,400 km²; about 60% of this is covered by vegetation which is equivalent to about 28 million hectares (Mha) as of the year 2000. From the 28 Mha, about 12 Mha are covered by tropical rainforest, an equivalent of 42% of the total vegetative area (FAO, 2009). Within the decade 1990-2000, about 220 thousand hectares of forests and grasslands were lost each year in Cameroon; this gives rates of between 0.6-1.0 percent of annual loss of forest in Cameroon (FAO, 1990; FAO, 2010b).

Many studies have discussed deforestation in Africa (Arementeras *et al.*, 2010; Lambin and Ehrlich, 1997; Mertens and Lambin, 1997; Agvei, 1997; Agarwal *et al.*, 2005; Oyono, 2005). However, a lot of gaps in research still exist in many countries in general and Cameroon in particular. This is because there has been a remarkable absence of a systematic and adequate analysis of the major factors that cause deforestation (Salam and Noguchi, 1998). Most of the studies written on Africa, Asia and Latin America have simply attributed the loss of forests to population growth, shifting cultivation, economic development, misplaced and poorly guided government policies, conversion of forests into agricultural land, commercial logging and fuel wood fetching/gathering among others without any hypotheses and tests. These studies lack a lot of empirical support to validate their assertions and have not been able to classify the causes to come out with a rank of causal factors. The lack of empirical support is evident as most of the past studies have been mainly descriptive with generalizations of the causes of deforestation (Salam and Noguchi, 1998; Allan and Barnes, 1985; Fischer and Vasseur, 2000; Carr *et al.*, 2005).

The objectives of this study are to examine the causes of forest area loss/deforestation in Cameroon through statistical models determined by a multiple linear regression approach which will enable a classification of the most important causal factors. The key variables that will be analyzed in the linear regression equation will be: forest

area, cattle stock, arable output per capita, arable and permanent crop land, rainfall, trade in forest products or logging, population and fuel wood. This approach is important because to be able to control the ecological and social effects of deforestation and to enact adequate policies it is important to have a close look at the causes on a broad national scale. To our knowledge, this is the first study that has applied this approach in looking at the causes of deforestation in Cameroon. The approach remains vital because if we plan to subvert food and water scarcity as is the case in Somalia and,” If we hope to conserve forests, we must understand the reasons that people are destroying them” (Acheson and McMclosky, 2008).

2.4. STUDY AREA AND METHODOLOGY

2.4.1. Study area

In this study, a national scale approach has been adopted to determine the variables that are more important in causing forest loss in Cameroon. In Cameroon, forests are essentially dominant in the south. As we move northwards, we have the Adamawa region and the North region which are dominated by essentially tropical grassland called Sudan savanna. The region that is south of the Adamawa is covered by tropical grasslands of the Guinea savanna type. The extreme north region is covered by Sahel savanna (Mertens and Lambin, 2000) (Figure 2.1). However, we can also find tropical moist deciduous forests in the Adamawa, tropical dry forests in the North and tropical shrub land forests in the Sahel (FAO, 2010a). Therefore, though most of Cameroon’s forests are in the south of the country, we also have some in the North which is also of great importance considering the fragile nature of the ecosystem. The forests of Cameroon are generally vital because they are part of the Congo basin forests of Africa which remains the second largest stock of tropical rainforest in the world (FAO, 2010a).

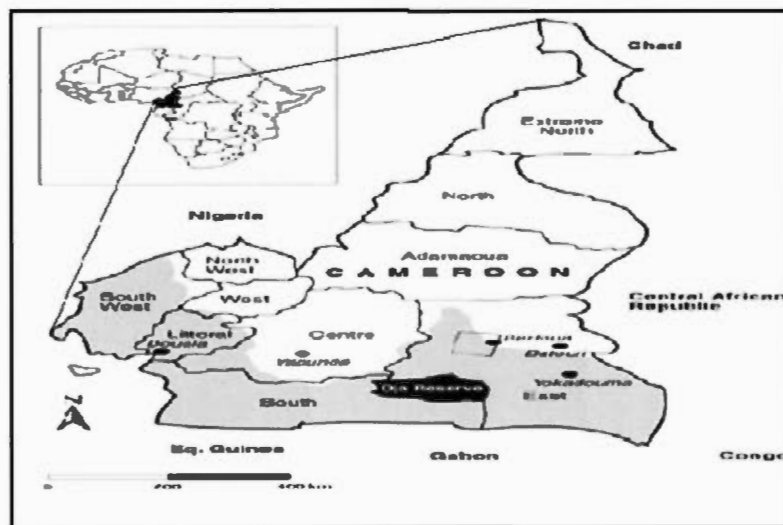


Figure 2.1. Map of Cameroon showing approximate spatial extent of the forest area shaded in light grey. The regions to the north are dominated by essentially tropical grassland ranging from Sudan savanna in the Adamawa and North regions, Sahel savanna in the Extreme North and Guinea savanna in the transition zone between the south of the country and the north of the country

Source: Modified from Mertens and Lambin, (2000).

2.4.2. Data collection

In an attempt at exploring the relative importance of the different factors responsible for deforestation in Cameroon, several data bases were consulted and used to generate the data. The data on forest area, cattle stock, arable production, trade in forest products/logging and arable and permanent crop land were obtained from FAO, (2010a) (www.faostat.org) and the data bases of the World Resource Institute (earthtrends.wri.org). It is worthy of note that most of the data from the FAO are based on country reports which have been criticized as coarse and highly approximate. With this in mind, all FAO data for Cameroon has been verified with those of World Resource Institute for coherence. To further improve the reliability of the data, on the ground observations were carried out. In general, the results show

close correlations between FAO, WRI estimates and ground observations. The rainfall data was obtained from a collaborative climate data base of the school of Geography and the Environment of the University of Oxford and the United Nations Development Program (www.country-profiles.geog.ox.ac.uk). Finally, the population data for Cameroon was obtained from the World Bank, World Development Indicators data base (www.google.com/publicdata). All the data used in this study were time series data for each variable covering the period 1961-2000. This study is limited only to the variables mentioned above due mainly to issues of data availability.

2.4.3. Data analysis

To verify the strength of the factors affecting forest area, a multiple linear regression analysis approach was used to determine the effects of the independent factors on the dependent factor. The open R programming statistical software version 2.12.0 was used to analyze the data. The dependent variable was: Total forest area in hectares. The independent variables were: cattle stock in heads, arable production per capita index in international dollars, fuel wood in cubic meters, arable and permanent crop land in hectares, rainfall in millimeters, population and trade in forest products/logging in international dollars. The model assumes that forest area is declining by 220 Kha/year (FAO, 2010b).

The model, variables and regression equation used in the R programming interface for statistical analysis are:

$$\text{fit} = \text{lm} (\text{ForestArea} \sim \text{CattleStock} + \text{ArableProd} + \text{FuelWood} + \text{ArablePCL} + \text{Rainfall} + \text{POPS} + \text{Tradeforest})$$

Alternatively, this can be stated as:

$$\text{FA} = \text{F} (\text{CS} + \text{AP} + \text{FW} + \text{APCL} + \text{RF} + \text{POPS} + \text{TF})$$

Where:

- lm is the linear regression model used in the R interface

- ForestArea (FA) is the Total forest area in thousand hectares (Dependent variable)
- CattleStock (CS) is Cattle stock in thousand heads (Independent variable)
- ArableProd (AP) is Arable production per capita index in international \$ (Independent variable)
- FuelWood (FW) is fuel wood in thousand cubic meters (Independent variable)
- ArablePCL (APCL) is arable production and permanent crop land in thousand hectares (Independent variable)
- Rainfall (RF) is rainfall in mm (Independent variable)
- POPS (POPS) is the population (Independent variable)
- Tradeforest (TF) is trade in forest products/logging in international \$ (Independent variable)

The model was run in R as stated above and this was followed by a sequential removal of variables that showed a lot of collinearity to optimize the model. These variables are removed not because they are unrelated to the dependent variable but because they don't bring in any additional information into the model. This optimization was done by removing variables that had the highest p-value until only those with p-values less than 0.05 remained. The regression model equations used for removal and rerun after removal of variables was as follows:

Remove Cattle Stock

fit = lm (ForestArea ~ ArableProd + FuelWood + ArablePCL +Rainfall + POPS + Tradeforest) or

FA= F (AP+ FW+ APCL+ RF+ POPS+ TF)

Remove Fuel Wood

fit = lm (ForestArea ~ ArableProd + ArablePCL +Rainfall + POPS + Tradeforest) or

FA= F (AP+ APCL+ RF+ POPS+ TF)

```
## Remove Trade Forest
```

```
fit = lm (ForestArea ~ ArableProd + ArablePCL + Rainfall + POPS) or
```

```
FA= F (AP+ APCL+ RF+ POPS)
```

```
## Remove Rainfall
```

```
fit = lm (ForestArea ~ ArableProd + ArablePCL + POPS) or
```

```
FA= F (AP+ APCL+ POPS)
```

As seen above, the final model included population, arable and permanent crop land and arable production per capita index. The variables removed included cattle stock, fuel wood, trade in forest products/logging and rainfall. A correlation matrix was created on the data; this was done to see the degree of correlation that exists between all the variables included in the study. The equation used to create this was as follows:

```
## Create a correlation matrix for the data
```

```
cor (raw_dat)
```

Where: cor stands for correlation in the R interface and raw_dat represents the raw data used in the calculations.

Finally, to determine the strength of the model in predicting the variables and their effects on forest area, power analysis was employed. Normally, with an R^2 that is close to 1, it can be said that the model is exceptionally powerful and useful in predicting the dependent variable. However, to verify this, the power analysis approach was used and run in R. The formula and procedure for such calculations is as follows (Cohen, 1988):

```
> ## Power Analysis of Final model
```

```
> fit = lm (ForestArea ~ ArableProd + ArablePCL + POPS)
```

```
> effect=Rsqr/ (1-Rsqr)
```

Where: $Rsqr = R^2$ (coefficient of determination)

u = Degree of freedom of numerator or sample =3

v = Degree of freedom of the denominator =36

Level of significance = 0.05

2.5. RESULTS

2.5.1. Time series plots of independent and dependent variables

The variables included in the multiple linear regression equation were plotted over time to illustrate their trends. Eight time series plots were obtained. It is observed that the dependent variable which is the forest area is perfectly linear. This is explained by the fact that this model assumes a yearly loss in forest area of 220 Kha inspired from (FAO, 1990; FAO, 2010b). For the first four variables (Figure 2.2), the following observations were made. Cattle stock on its part is generally increasing from year to year. This is explained by the fact that keeping cattle is an economically enriching activity and years of profit made and increase in population encourage more production. Arable production per capita index is highly variable, it was rising in the beginning right up to around 1974 and thereafter it begins to decline. The decline is explained by the surge in droughts in the late 1970s and early 1980s and the rise though extremely very low is due to rising rainfall during the 1990s. Fuel wood on its part was constant in the beginning and then experienced a rise explained by population increase and the fact that fuel wood is a very important source of energy to most households in Cameroon.

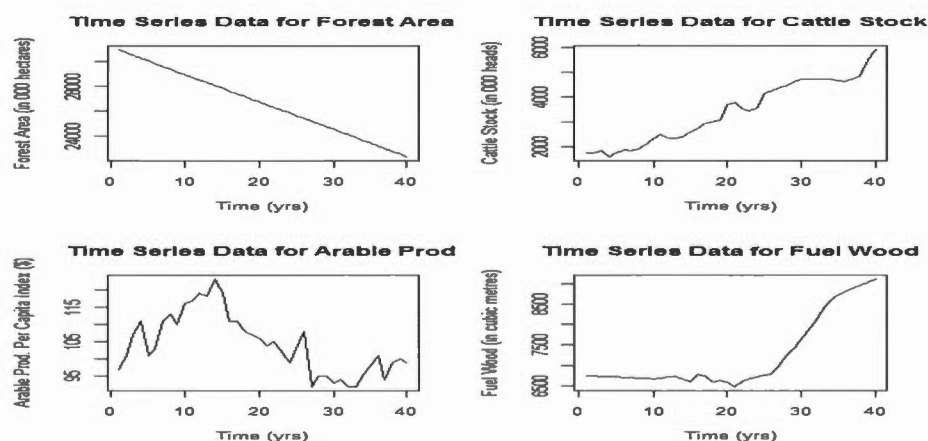


Figure 2.2. Time series plots of forest area, cattle stock, arable production and fuel wood. The years range from 1961-2000. Note that 0 years on year's axis represents 1960, 10 years represents 1970, 20 years represents 1980, 30 years represents 1990 and 40 years represents 2000.

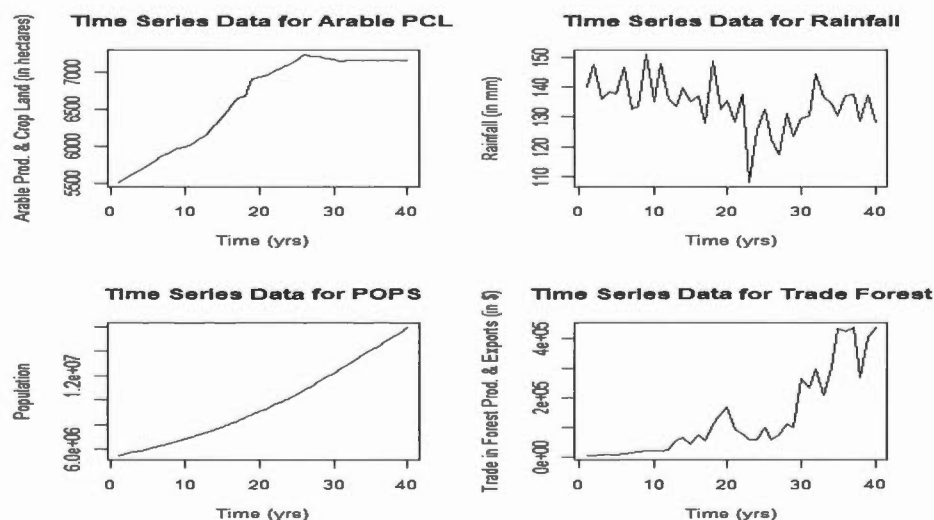


Figure 2.3. Time series plots of arable and permanent crop land, rainfall, population and trade in forest products. The years range from 1961-2000. Note that 0 years on the year's axis represents 1960, 10 years represents 1970, 20 years represents 1980, 30 years represents 1990 and 40 years represents 2000.

For the last four variables (Figure 2.3) it is observed that arable and permanent crop land rose steadily during the first half and leveled. The rise is due to the increase expansion of farms while leveling could be explained by the fact that land is a fixed asset and even when expansion slows, a given minimum amount of land is still under production. Also, a surge in cash crop farming which reduced food crop production and the implementation of policies to halt continual expansion of farm land in an attempt to reduce forest loss may be plausible; this coincided with the National Environmental Management plan which stated measures to enhance environmental management. Rainfall on its part is generally fluctuating throughout the period and the recurrent droughts can be used to explain its pattern. The generalized trend is one of a “white noise” which depicts a very variable random variable as it hardly correlates with any of the variables significantly. However, it observes rising trends from the early 1990s. The population trend on the other hand depicts an increasing exponential population over the entire period. In 1961 the population was about 5 million people but by 1984 it had doubled itself and stood at about 10 million while by 2000 it was about 15 million people. Trade in forest products/logging was increasing as well but also has some slight variations. The trend is explained by rising population and increase profitability in wood exports and slight fluctuations explained by low demand for Cameroon’s hard wood at the world market due to processing difficulties.

2.5.2. Scatter plot matrices between various independent factors and forest area

A simple scatter plot matrix (Figure 2.4) was setup to look for relationships among all the variables. From the observed correlations, it can be observed that almost all the variables are interrelated. The only plots that appear to have weak trends are the plots of all other variables against rainfall. The rest of the variables seem to cause a decline in forest area. Both population and cattle stock appear to be highly co-linear with forest area. This is indicative of the fact that both population and cattle stock are

closely correlated. When population rises, cattle stock rises and this also causes forest area to decline.

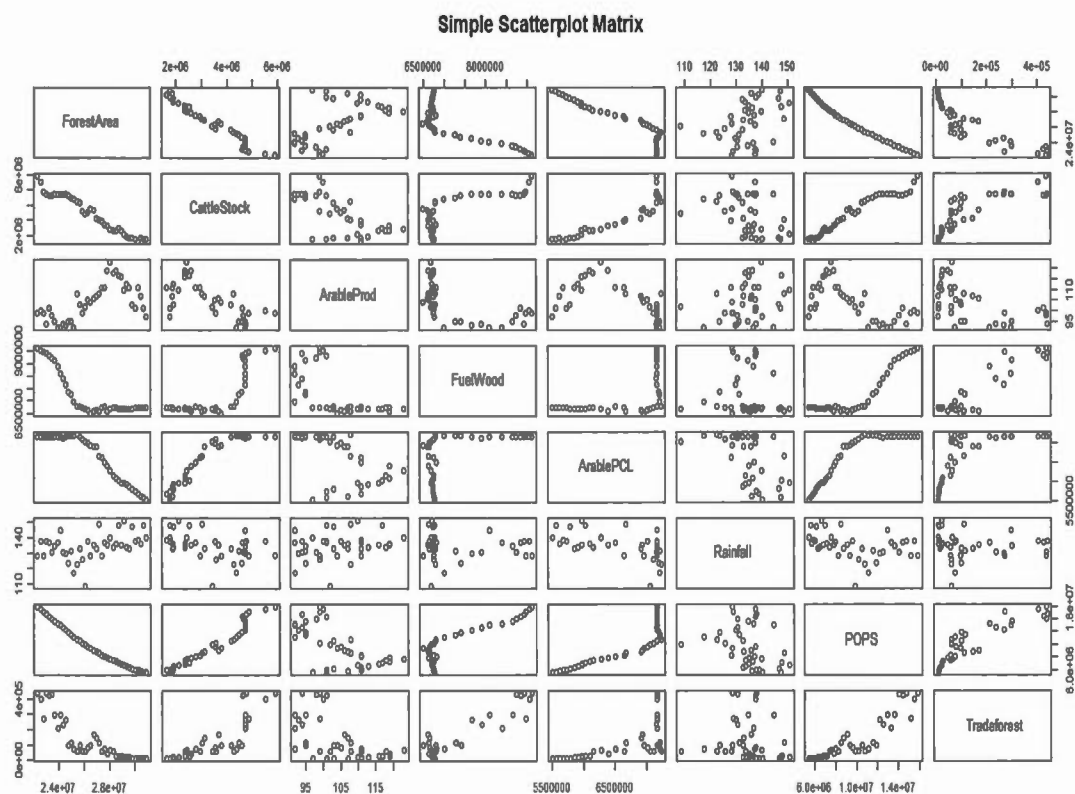


Figure 2.4. Scatter plot matrix illustrating relationships between all pairs of variables. We observe that all variables have a negative correlation with forest area except rainfall.

With regards to the relationship between population and forest area on one hand and cattle stock and forest area on the other (Figure 2.5), there is an inverse relationship. The cattle stock component spirals around the best fit line suggesting a cyclical component which in this case could be explained by years of increase cattle stock followed by years of low cattle stock and years of low cattle stock followed by years of increase cattle stock. There is therefore a possibility for high dependence between

cattle stock and population as both variables seem to be highly correlated. This will however be confirmed when a correlation matrix will be built.

Scatter Plots with Best Fit Lines

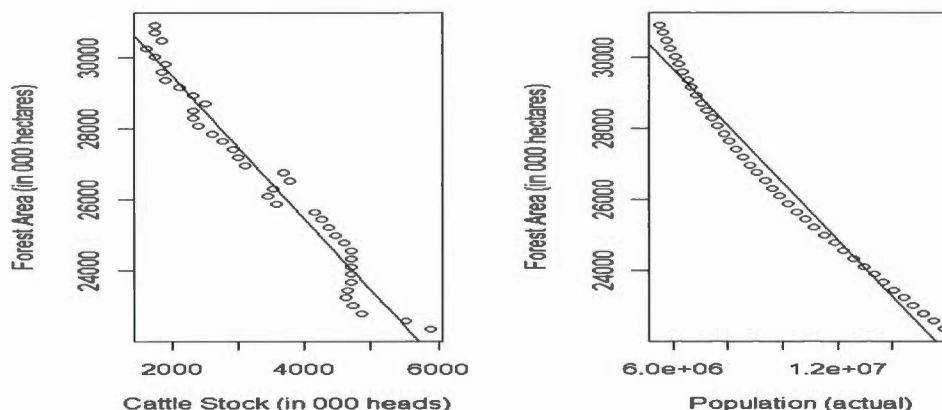


Figure 2.5. Scatter plots of cattle stock and population against forest area. Scatter plots with best fit lines showing a generalized trend of decline in forest area with increase cattle stock and population.

Similarly, arable and permanent crop land and fuel wood also seems to be increasing over time. However, when fuel wood was constant, arable and permanent crop land was rising while when fuel wood was rising, arable and permanent crop land was constant (Figure 2.6). This is because from the 1990's the economic crisis caused fuel wood to become a major source of both energy and income due to wide scale commercialization. At this same time, the disincentives obtained from arable production caused many farmers to abandon the expansion of their farms in the 1990's.

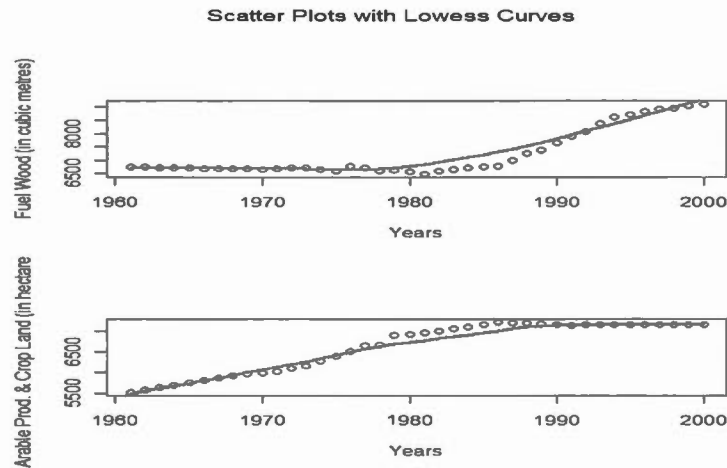


Figure 2.6. Time plots for Fuel Wood and Arable PCL. Scatter plots with Lowess curves. We observe that when fuel wood is constant, arable production and permanent crop land are rising and when fuel wood is rising, arable production and permanent crop land are constant.

2.5.3. Correlation matrix of independent and dependent variables

From the correlation matrix (Table 2.1), cattle stock has a correlation of ($r = -0.98$) with forest area, fuel wood has a correlation of ($r = -0.81$) with forest area, population has a correlation of ($r = -0.98$) with forest area and trade in forest products/logging has a correlation of ($r = -0.86$) with forest area. The implication of these results is that all these variables are strongly negatively correlated with forest area and as such when they increase, forest area decreases.

Generally, many of the independent variables are highly correlated with each other. This suggests that collinearity is a significant problem in building a multiple regression model. A Pearson correlation coefficient of 0.8 will be problematic if placed in the model. Removal of variables will be considered during the stepwise process utilized to build the regression model.

Table 2.1. Correlation Matrix for All Variables under study

	Forest Area	Cattle Stock	Arable Production	Fuel wood	Arable production and permanent crop land	Rainfall	Population	Trade in forest products and logging
Forest Area	1.0	-0.98	0.59	-0.81	-0.93	0.39	-0.98	-0.86
Cattle Stock	-0.98	1.0	-0.66	0.77	0.92	-0.40	0.97	0.82
Arable Production	0.59	-0.66	1.0	-0.58	-0.56	0.24	-0.64	-0.54
Fuel wood	-0.81	0.77	-0.58	1.0	0.55	0.07	0.88	0.92
Arable production and permanent crop land	-0.93	0.92	-0.56	0.55	1.0	-0.51	0.87	0.67
Rainfall	0.39	-0.40	0.24	-0.07	-0.51	1.0	-0.34	-0.08
Population	-0.98	0.97	-0.64	0.88	0.87	-0.34	1.0	0.90
Trade in forest products and logging	-0.86	0.82	-0.54	0.92	0.67	-0.08	0.90	1.0

The unknowns with abbreviations are Arable Prod which stands for Arable production per capita index and ArablePCL stands for Arable and permanent crop land in hectares, POPS which represents population and Tradeforest which represents trade in forest products in international \$. POP, Cattle stock, fuel wood ArablePCL, Tradeforest are strongly negatively correlated with forest area.

2.5.4. Multiple linear regression models of forest area and the independent variables

The first run of the multiple linear regression model considered all the seven independent variables listed on Table 2.2 relative to the dependent variable and the results obtained from the runs are as follows. The general performance of this model is depicted in an f-statistic of 3486 which means the model is fairly significant. The f-

statistics is used to determine the significance of the regression parameters. In other words it is used to validate or invalidate the null hypothesis. If the f-statistic is zero then all the coefficients of the model are zero and the null hypothesis is valid; anything above zero depicts some level of significance. This is further supported by a p-value of <2.2 and a coefficient of determination or multiple R^2 of 0.9887. The p-value of cattle stock is listed as 0.945. This number should not be interpreted as meaning cattle stock is not significantly related to forest area, rather, what is happening is that cattle stock is so highly correlated to population such that as stated earlier collinearity arises. This high p-value means that with population in the model, cattle stock does not bring in enough new information to justify its inclusion. However, the three most significant variables that influence forest area as per this model are arable production per capita index (-6.9), arable and permanent crop land (-6.4) and population (-5.5). Generally, variables with the higher t-values are more significant (Table 2.2).

Table 2.2. First run of linear regression model with all independent variable

Variables	Coefficient	Standard Error	t- value	p-value	Rank of t-value
Cattle Stock	-6.70	9.57	-0.070	0.94	
Arable Production	-1.96	2.81	-6.960	6.96***	1
Fuel wood	-1.83	1.99	-0.919	0.36	
Arable production and permanent crop land	-1.45	2.24	-6.458	2.90 ***	2
Rainfall	-3.90	2.61	-1.492	0.14	
Population	-5.63	1.00	-5.588	3.58 ***	3
Trade forest	4.84	3.92	1.235	0.22	

Total number of independent variables =7, residual standard error = 102.5,

degree of freedom = 32, multiple r-squared = 0.9887, adjusted r-squared = 0.9984,

f-statistic = 3486, on 7, p-value = $< 2.2e-16$, significant codes = *

Residuals:

Min	1Q	Median	3Q	Max
-157.541	-68.390	-9.338	72.475	248.269

Table 2.3. Final run of linear regression model with the three most significant independent variables

Variables	Coefficient	Standard Error	t -value	p-value	Rank of t-value
Arable Production	-1.88	2.49	-7.5	6.19 ***	3
Arable production and permanent crop land	-1.21	5.59	-21.7	$< 2e-16$ ***	2
Population	-6.25	1.15	-54.4	$< 2e-16$ ***	1

Total number of independent variables = 3, residual standard error = 102.4,

degree of freedom = 36, multiple r-squared = 0.9885, adjusted r-squared = 0.9984,

f-statistic = 8156 on 3, p-value = $< 2.2e-16$, significant codes = *

Residuals:

Min	1Q	Median	3Q	Max
-138.338	-92.888	-6.522	72.171	259.645

The variables that were removed to optimize the model are: cattle stock, fuel wood, trade in forest products/logging and rainfall. The final model therefore included population, arable and permanent crop land, and arable production per capita index, essentially the variables that were dominant in the first run. From the rerun, it is

observed that there is an R^2 of 0.9885. This implies that the model containing only these three variables significantly explains the variations in forest area. From the individual t-values, we observe that population stands out as the most influential independent variable affecting forest area; this is followed by arable and permanent crop land and finally by arable production per capita index (Table 2.3). Also, the f-statistic of the final model is greater than that for the initial model meaning that the final model is more significant.

To determine the strength of the model, a power test was run in the R interface. However, it is intuitive that, with an R^2 value of nearly 1, the power of this model is exceptionally high. However, it is still necessary to verify this. To do so, the R statistic power package was utilized. This method calculates power using the methods outlined by Cohen, (1988). The output is shown below. The result of the power test is estimated at 1, showing that the model is still highly significant in predicting deforestation. The initial model suffers from collinearity and interdependence among some of the independent variables as well as the fact that the trends in the annual change in forest area are set at a constant rate of 220 Kha per year, this is however the established rate for the decade 1990-2000 (FAO, 2010b). To overcome these difficulties, the model has been optimized as some of these variables have been dropped in the later model.

2.6. DISCUSSION

The final linear regression model reveals that population growth is at the centre forest area loss. This is because as population grows, the need for more land for agriculture and settlement inter alia increases. According to Index Mundis, a free online data base available on (www.indexmundi.com) Cameroon had a population growth rate of 2.12% in 2011 and 2.47% in 2000. Other studies have reported similar results that support this view point. Allen and Barnes (1985) used a multiple regression approach to confirm that increase in population was more associated to loss in forest area in Africa and Asia while arable expansion was also considered as the second variable.

Acheson and McClosky, (2008) also conclude in their study on the causes of deforestation in Maine that population growth is a major trigger. In Bangladesh, it is reported that population growth poses a big problem of over exploitation of forest resources as extreme population growth has been eating up forest resources at a rate faster than they can be regenerated. Increase arable land is also considered as a factor of importance, it is argued that the quest is driven by the rapidly growing population (Salam and Noguchi, 1998). Furthermore, population dynamics have been widely considered as elements in land cover change dynamics. In fact, population has been described in the literature as one of the significant drivers of global deforestation (Carr *et al.*, 2005; Vanclay, 1993; Houghton, 1991; Zhao *et al.*, 2006). Other studies argue that population growth explains more than half of the loss in forest area worldwide (Mather *et al.*, 1998; Myers, 1991). However, Angelsen and Kaimowitz (1999) argue that in addition to population it would be good to consider other factors such as cropland expansion and cattle ranching. In as much as this is true, the connection in all these studies is that as population grows, the need to feed more mouths increases and this often means more forest clearance.

Other factors that are considered important are arable and permanent crop land as well as arable production per capita index which are second and third most valuable factors that explain deforestation in Cameroon. This result is highly consistent with other studies. A study carried out in central Argentina reports that the agricultural expansion for the purpose of cultivating Soya beans in particular is the main proximate cause of forest loss (Zak *et al.*, 2008); a view supported by Geist and Lambin, (2002), when they report that about 96% of deforestation in Africa, Asia and Latin America is caused by agricultural expansion. As such, agricultural expansion remains a vital cause of deforestation and it at times comes up due to population pressure. In supporting the latter notion it has been stated that one of the principal causes of deforestation in Panama has been the expansion of agricultural frontiers through extensive shifting cultivation systems. The study adds that the land use

systems are becoming increasingly problematic because as population rises, the amount of agricultural land available for use declines and this triggers deforestation in search for more land and fuel wood (Fischer and Vasseur, 2000). The role of fuel wood in sub-Saharan Africa has been explored in the literature. About 90 percent of the population in sub-Saharan Africa use fuel wood which contributes about 52% of the entire African energy budget (Agvei, 1997). In Bolivia, mechanized agriculture, small scale agriculture and cattle ranching have been observed as the major drivers of deforestation in order of importance (Muller *et al.*, 2013).

2.7. CONCLUSIONS

This study shows that the most significant causes of loss in forest area in Cameroon are population growth, arable and permanent crop land and arable production per capita index. Currently, forest degradation in Cameroon is persistent and lack of knowledge of the actual causes has made attempts at reducing deforestation generalized, simplistic and the repercussions of food and water scarcity persist.

With these results, it therefore becomes possible for the government of Cameroon to target policies towards ones that will meet the needs of the populations by taking them off forest lands in attempts to create more space for agricultural expansion. If the government ignores this, the ecological consequences of deforestation will persist and further forest area loss will be the result. Therefore, policies that will reduce the rate at which the growing population encroaches on forested land should be enacted. These should however be in a context where the population is given more access to farm inputs such as fertilizers and machinery to enhance output on the same land.

Other possible independent variables not considered by these models are soil erosion, wild fires, acid rains and loss in soil fertility. These variables may affect forest loss, arable production and arable and permanent crop land. However, due to the difficulties associated with calculating these variables, inclusion in the model and collinearity, these variables have been left out of this current study.

2.8. ACKNOWLEDGEMENTS

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2.9. APPENDIX

Table 2.4.Core variables under consideration

Years	ForestArea(y) (in 000 hectares)	CattleStock (in 000 heads)	Arable Production per capita index (international \$)	FuelWood(in 000 cubic metres)	Arable production and permanent crop land (in 000 hectares)	Rainfall (in mm)	Population	Trade in forest products/exports (in international \$)
1961	30907	1750	97	6750	5510	139.92	5524197	6148
1962	30687	1750	101	6741	5570	147.38	5646209	6304
1963	30467	1850	107	6732	5620	135.89	5774035	7416
1964	30247	1600	111	6724	5680	138.54	5907535	9602
1965	30027	1740	101	6715	5740	137.78	6046694	9899
1966	29807	1882	103	6706	5800	146.59	6191813	12121
1967	29587	1850	111	6697	5870	132.48	6343314	13732
1968	29367	1900	113	6689	5920	133.55	6501453	18330
1969	29147	2100	110	6680	5970	150.73	6666501	20150
1970	28927	2325	116	6672	5978	134.91	6838792	21305
1971	28707	2500	117	6694	6028	147.64	7018240	22369
1972	28505	2325	119	6733	6095	136.13	7205237	24533
1973	28285	2325	118	6731	6160	133.43	7401135	55225
1974	28065	2400	123	6666	6280	139.73	7607665	63928
1975	27845	2600	119	6594	6395	134.91	7825971	44288
1976	27625	2750	111	6787	6510	136.77	8056997	73315
1977	27405	2917	111	6738	6644	127.99	8300237	56535
1978	27185	3000	108	6596	6671	148.59	8553609	108463
1979	26965	3100	107	6631	6912	132.7	8814133	144583
1980	26745	3681	106	6586	6930	135.41	9079803	167628
1981	26525	3782	104	6480	6960	128.37	9349359	93848
1982	26305	3512	105	6612	7010	137.39	9623779	76696
1983	26085	3431	102	6664	7060	108.21	9902962	58143
1984	25865	3561	99	6730	7110	125.48	10200049	60055
1985	25645	4151	103	6763	7160	132.58	10508768	97701
1986	25425	4255	108	6778	7230	122.49	10832848	60043
1987	25205	4362	92	6987	7210	117.26	11170539	73762
1988	24985	4471	95	7265	7210	130.95	11519006	112673
1989	24765	4582	95	7388	7190	123.45	11874217	99833
1990	24545	4697	93	7648	7170	129.5	12232973	265451

1991	24325	4700	94	7887	7150	130.41	12594697	234532
1992	24105	4700	92	8087	7160	144.46	12959446	295604
1993	23885	4700	92	8382	7160	136.7	13325466	209312
1994	23665	4700	95	8624	7160	134.45	13690847	299061
1995	23445	4650	98	8722	7160	130.41	14054403	434121
1996	23225	4623	101	8819	7160	137.1	14415168	424069
1997	23005	4737	94	8915	7160	137.6	14773789	436161
1998	22785	4846	99	8957	7160	128.45	15132782	268232
1999	22565	5500	100	9033	7160	137.37	15495758	401790

CHAPTER III

THE ENVIRONMENTAL QUADRUPLE: FOREST AREA, RAINFALL, CO₂ EMISSIONS AND ARABLE PRODUCTION INTERACTIONS IN CAMEROON

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3.1. RÉSUMÉ

Les déclencheurs de la perte de secteur des forêts au Cameroun n'ont pas été correctement compris. Les mesures employées pour limiter la perte de secteur des forêts ont été simplistes, généralisées sans la connaissance définie du rôle spécifique de différents facteurs potentiels. Cette étude vise à étudier l'hypothèse que la croissance démographique est la cause principale de la perte des forêts. Cette étude pourra identifier les facteurs qui sont les plus importants dans l'équation causale. Logiciel de programmation ouvert R a été employé pour produire des modèles linéaires multiples. La corrélation entre la variable dépendante (forêts) et les variables indépendantes a été établie par une matrice de corrélation et la force des modèles examinés par analyse de puissance. La croissance démographique est la cause la plus dominante du déboisement au Cameroun tandis que la production agricole est la deuxième.

3.2. ABSTRACT

This paper evaluates the interactions between forest area, CO₂ emissions, rainfall and arable production at a national scale in Cameroon. The data used for this analysis was essentially time series data for all the variables spanning the period 1961-2000. It uses regression analysis to determine the most important of these variables that affects CO₂ emissions and uses correlation analysis and coefficient of determination to verify the nature of the interactions between the variables. The results show that as forest area reduces there is an increase in CO₂ emissions concentration in the air in Cameroon. On the other hand, as forest area and rainfall reduce, arable production also reduces but forest area is seen to be more responsible for changes in arable production than rainfall. The study concludes that the interactions between CO₂ and forest area, arable production and forest area seem to be the most significant while rainfall is denoted as very variable from year to year. The main criticisms of this chapter are that some of the variables suffer from multi-collinearity while the models assume a constant yearly rate of decline in forest area of 220 Kha/year.

Keywords: forest area; co₂ emissions; rainfall; arable production.

3.3. INTRODUCTION

The interaction between CO₂ emissions, rainfall, arable production and forest area is very vital (Pielke *et al.*, 1998). In general, CO₂ emissions have recently occupied a central stage in environmental discussions because they do not only cause global warming but also affect the world's forests and food production systems (Zhang and Justice, 2001). Rainfall on its part has been known for decades to be a very important factor when it comes to the survival of trees and crops and generally, it is common knowledge that water remains a very important resource for humans (Epule *et al.*, 2011a). Globally, forests have been known for their ability to sequester CO₂, protecting our catchment areas and thus managing the land phase of the hydrological cycle (Zhang and Justice, 2001). The absence or disappearance of forests would have astronomic effects on the environment among which will be an increase in atmospheric CO₂ (Aber, 2001). The importance of arable production cannot be over emphasized. Food production systems are of great importance to humankind, yet they survive at the expense of large expanses of forests (Pielke *et al.*, 1998).

Cameroon is host to part of the tropical rainforest of the Congo basin which is the second largest rainforest hotspot in the world (FAO, 2010). As such, the trends of forest area loss in Cameroon will greatly affect the amount of CO₂ that can be sequestered and this will have a feedback on arable production sub-system and water resources on the land phase of the hydrological cycle (Zhang and Justice, 2001). On the other hand, agriculture is said to be responsible for 96% of the deforestation in most of Africa, Asia and Latin America in general and Cameroon in particular (Epule *et al.*, 2011b; Geist and Lambin, 2002).

Much work has already been done in the area of quantifying the causes of forest area loss in Cameroon, establishing the lost forests based on satellite images and determining the relative importance of rainfall and deforestation in affecting cereal production (Epule *et al.*, 2011b; Lambin and Ehrlich, 1997; Mertens and Lambin,

2000; Mertens and Lambin, 1997). However, the interactions between CO₂ emissions, rainfall, arable production and forest area have not been given adequate attention. This study therefore seeks to verify how forest area dynamics influences CO₂ emissions, rainfall, and arable production and how rainfall affects arable production and CO₂ emissions. This approach is vital because a holistic approach of most environmental variables can be explained better from a systemic approach rather than in isolation (Lambin and Ehrlich, 1997).

3.4. MATERIALS AND METHODS

3.4.1. Study Area

This study is a national scale study that covers data for all of Cameroon. The intention of analyzing the interactions between forest dynamics, rainfall, CO₂ emissions and arable production at a national scale is guided by the fact that such a scale permits adequate review of the situation as it takes into consideration various regional disparities that are often absent in smaller scale analysis (Lambin and Ehrlich, 1997).

Cameroon is located between latitude 2° N and 13° N of the equator and longitude 8° E and 15° E of the prime meridian (Molua, 2006; Molua and Lambi, 2006) (Figure 3.1). In the South of the country we have an equatorial climate and a Sahelian climate in the North. The South has more than 1500 mm of rain yearly that is fairly distributed all year round with average annual temperature of about 25°C and deep red ferrallitic soils (Molua, 2006; Molua and Lambi, 2006). In the North, annual average rainfall drops to about 400 mm around Lake Chad with temperatures of about 28°C and the soils are essentially ferruginous (Molua, 2006).

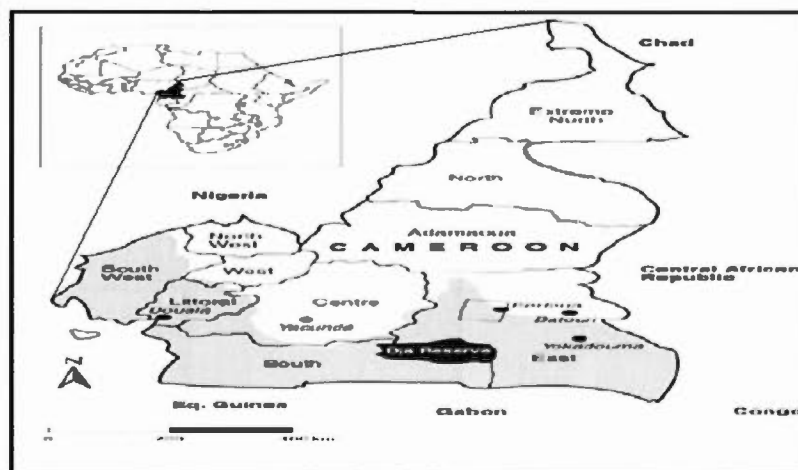


Figure 3 .1. Map of Cameroon showing approximate spatial extent of the tropical rainforests (shaded in light grey) and the grasslands

Source: Modified from Mertens and Lambin, (2000).

3.4.2. Data Collection

To be able to explore the interactions between forest area, arable production, CO₂ emissions and rainfall in Cameroon and the importance of the variables that affect CO₂ emissions, a number of data bases were used. The data on forest area in thousand hectares (Kha), arable production per capita index in international dollars (\$), and CO₂ emissions from forest area change in thousand metric tons was obtained from (www.faostat.org) and validated with that from World Resource Institute (www.earthtrends.wri.org) (see appendix, Table 3.3). Rainfall data were obtained from the online climate data base co-sponsored by the school of Geography and the Environment of the University of Oxford and the United Nations Development Program (www.country-profiles.geog.ox.ac.uk). All the data were time series data spanning the period 1961-2000.

To actually generate the data, we opened the FAOSTAT and/or WRI data base interfaces, selected the variable of interest, the country and the years of interest for which data was needed and clicked search. With this the data (Table 3.3) was

populated on an excel sheet. For the purpose of verifying the reliability and validity of the data, ground observations and case study scale studies were conducted.

3.4.3. Data Analysis

The data were analyzed with the aid of the Statistical Package for the Social Sciences (SPSS) version 19 and the Sigma Plot version 11.0. Three principal analytic tools were applied. These included multiple linear regression analysis, Pearson correlation statistical tool and the coefficient of determination (Motulsky, 1999).

The multiple linear regression approach is used to verify the most significant determinants of CO₂ emissions in Cameroon at a national scale from the selected set of variables. The equation used to fit the multiple linear models is:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \epsilon_i$$

Where: y_i is the dependent variable (CO₂ emissions), β_0 is the intercept, β_1 , β_2 , β_3 , β_4 partial regression coefficients, x_{i1} , x_{i2} , x_{i3} , x_{i4} independent variables (forest area, rainfall and arable production), ϵ_i is the error term.

To determine the interactions between the selected variables, the following pairs of correlations were computed, note that the first variable in each pair is the independent variable (x) while the second is the dependent variable (y): (forest area and CO₂ emissions, forest area and rainfall, forest area and arable production, rainfall and arable production and rainfall and CO₂ emissions). The equation used to fit these models is:

$$r = \frac{\sum (x - \mu)(y - \mu)}{\sqrt{\sum (x - \mu)^2 \sum (y - \mu)^2}}$$

Where: r is the Pearson correlation coefficient, x is the independent variable, y is the dependent variable, μ is the mean of both variables, r ranges between - 1.0 and 1.0, where: -1.0 to - 0.7 strong negative association, -0.7 to -0.3 weak negative

association, - 0.3 to + 0.3 little or no association, + 0.3 to + 0.7 weak positive association, +0.7 to +1.0 strong positive association.

The coefficient of determination (R^2) was also used to determine how well the regression line represents the collected data and the extent to which variations in y are explained by the linear relationship between x and y. It ranges between -1 and 1. This is often computed by simply squaring the Pearson correlation coefficient (r).

3.5. RESULTS AND DISCUSSION

The linear regression outputs show that forest area is the most significant variable that affects CO₂ emissions. As forest area declines CO₂ emissions increase (Figure 3.2). Arable production and rainfall are second and third respectively. This is evident in the fact that forest area has a t-value of -21.32 which is the highest, heralding a larger effect on CO₂ and a p-value of 0.001 which is the smallest of all the p-values. This p-value shows that there is only a 0.1% chance of observing a difference in the result. Generally, the smaller the p-value, the more reliable the results are. Arable production has a t-value of -1.27 and a p-value of 0.086 (8.6%), this denotes an 8.6% possibility of a difference as large as observed while rainfall has a t-value of -0.61 and a p-value of 0.552 (55%), this denotes a 55% possibility of a difference as large as observed. From all indications, rainfall remains the most variable factor and its influence on CO₂ emissions is the weakest (Table 3.1).

Table 3.1. Linear Regression model with three most significant determinants of CO₂ emissions

Variables	Coefficient	Standard error	t-value	Rank of t-value	p-value
Forest area	-0.94	0.34	-21.32	1	0.001
Arable production	-0.05	95.59	-1.27	2	0.086
Rainfall	-0.02	78.46	-0.61	3	0.552

Time series plots of the evolution of forest area and total CO₂ emissions from forest area change are consistent with the regression analysis results and depict forest area in a declining linear trend while there is a rise in total CO₂ emissions. The linear trend of forest area is evident because the model assumes a constant yearly decline in forest area of 220 (Kha) inspired from (FAO, 1990; FAO, 2010) (Figure 3.2). The World Bank, (2011) supports this rising trend in CO₂ in Cameroon when it argues that the CO₂ emissions per capita in metric tons have risen from 0.09 in 1990 to 0.21 in 2005 to 0.24 in 2006 and to 0.34 in 2007.

However, the current trends of increase in CO₂ emissions are not as high as the 0.66 recorded in 1983. This is explained by the increase in newly established industries and wide scale reckless deforestation and a lack of compliance with regulations to curb emissions. The 1990s on the other hand saw the birth of the National Environmental Management Plan (NEMP) that called for enforcement of environmental regulations in Cameroon, the reason why the emissions from the 1990s are relatively lower than the period before (Biwas and Tortajada, 2011). The conclusion that CO₂ emissions are however rising in Cameroon is consistent with many other sources (Mundex Index, 2011; WRI, 2003; Detwiler and Hall, 1988; Lugo and Brown, 1992; Dixon *et al.*, 1994; Houghton, 1995; The World Bank, 2011).

In terms of scatter plots, an inverse relationship between forest area and total CO₂ emissions is observed (Figure 3.5). As forest area reduces, CO₂ increases and vice versa. This model appears to be the most reliable of all the models as already mentioned above because it has an R² of 0.963 which signifies that about 96% of the variations in CO₂ emissions are explained by the linear relationship between forest area and CO₂ emissions. The *r* of -0.981 also goes to reinforce the notion of a very strong negative or inverse association or correlation between forest area and total CO₂ emissions (Figure 3.5 and Table 3.2).

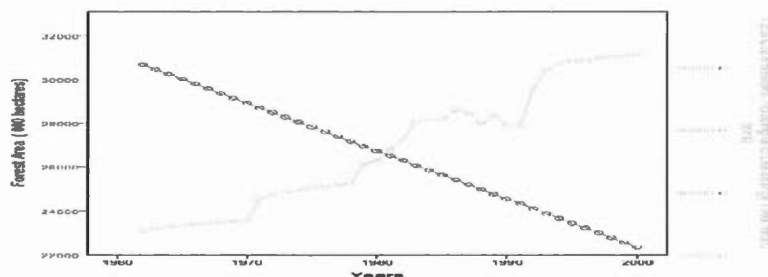


Figure 3.2. Time series plot of the evolution of Forest area and total CO₂ emissions.

The observed trends in rainfall can be described as a “white noise” since rainfall is a highly random variable which barely has a fixed trend and therefore remains highly variable. However, the generalized trend is that of higher rainfall before the 1960s, very low rainfall in the late 1960s and early to mid 1980s due to droughts and rising but highly variable rainfall from the 1990s with some years of increase and others of decrease. However, the 1990 levels of rainfall were much higher than what obtained in the later years; but between 1999/2000 a declining trend was observed (Epule *et al.*, 2012a) (Figure 3.3). This is closely consistent with several studies which argue that sub-Saharan African rainfall is highly variable yet increasing at the moment (Olsson and Mryka, 2008; Wang and Eltahir, 2000; Anyamba and Tucker, 2005). However, in terms of the influence of rainfall on CO₂ emissions, a very weak relationship is established (Table 3.1, Figure 3.9). This is explained by the fact that the very variable and increasing rainfall cannot be used to explain forest loss which is being impacted negatively by population growth through the increase demand for agricultural land (Olsson and Mryka, 2008; Epule *et al.*, 2012a).

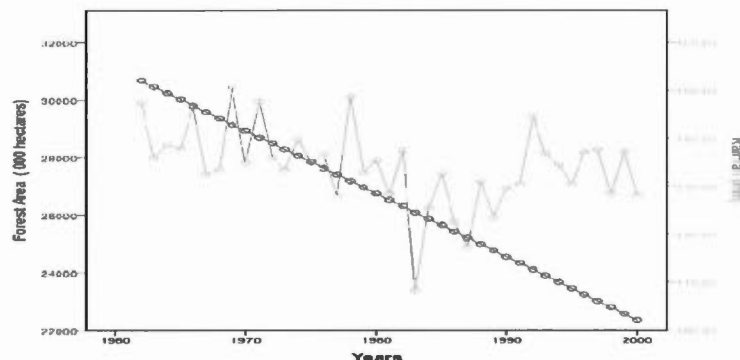


Figure 3. 3. Time series plot of the evolution of forest area and rainfall.

In terms of correlation between forest area and rainfall, we observe a relationship with an r of 0.377 which depicts a weak correlation. The slightly positive trend is explained by the variability of rainfall and the fact that at the end of the simulation (1999/2000) we observe declining rainfall. The R^2 of 0.142 depicts that only about 14% of the variations in rainfall are explained by the linear relationship between forest area and rainfall which remains very weak.

Though the relationship between forest area and rainfall is weak, an important view point here is that both forest area and rainfall are moving towards the same direction. The increasing greening observed in the Sahel from the 1990s is for example a reflection of the increase in rainfall (Olsson and Mryka, 2008; Eklundh and Olsson, 2003; Epule *et al.*, 2012a). This also helps us to conclude that when forest area declines it reduces the amount of water available in the ecosystem by disrupting the land phase of the hydrological cycle (Figure 3.6 and Table 3.2). On the other hand, rainfall is not a significant determinant of forest area dynamics because in spite of its increase, forest area decline is still being recorded (Epule *et al.*, 2011b).

Arable production per capita index also observes a generalized declining trend with declining forest area. The lowest levels in the series are obtained during the droughts of the 1980s when most of the moisture available from rainfall was not available for

crop growth (Figure 3.4). According to Epule *et al.*, (2012a) the fact that rainfall was rising in the mid 1990s and arable production still declined means that this decline is essentially explained by the large scale deforestation in Cameroon that affected food supplies. This argument is supported by Molua and Lambi, (2006) and Olsson and Mryka, (2008).

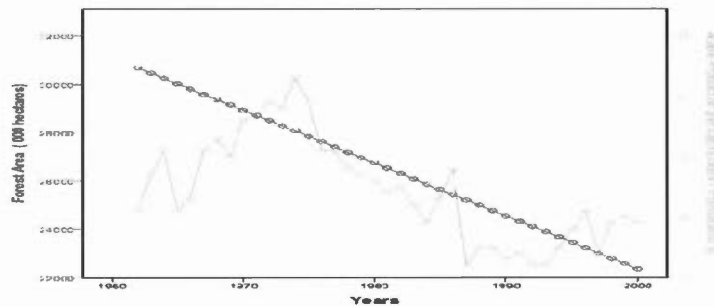


Figure 3.4. Time series plot of the evolution of forest area and arable production per capita index.

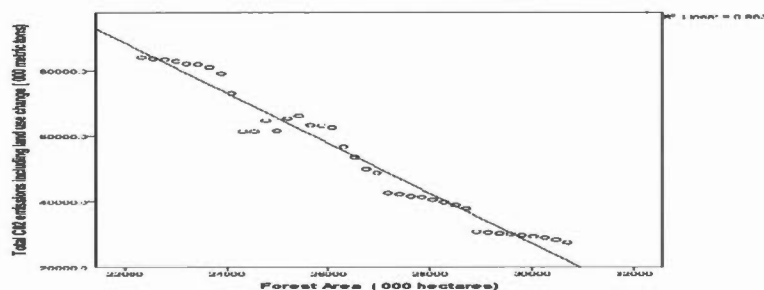
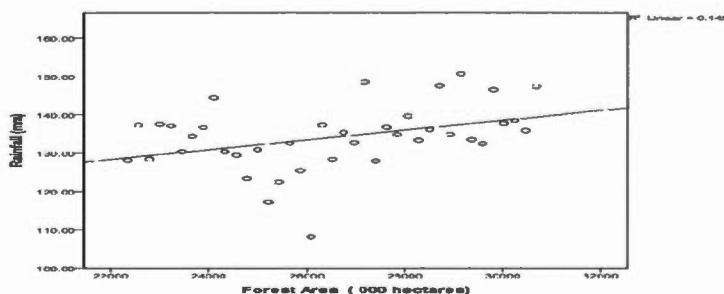


Figure 3.5. Scatter plot of the inverse relationship between forest area and total CO₂.

Table 3.2. Pearson correlation and coefficient of determination results of the model

Independent variables	Dependent variable	Pearson's r	R ²
Rainfall	CO ₂ emission	-0.389	0.151
Forest Area	CO ₂ emissions	-0.981	0.963
Forest Area	Rainfall	0.377	0.142
Forest Area	Arable production	0.668	0.446
Rainfall	Arable production	0.268	0.072

Forest area is expressed in (Kha), CO₂ emissions is expressed in thousand metric tons (Kmt), rainfall is expressed in mm and arable production per capita index in international dollars (\$). There are 40 years of time series data significant at 0.01 levels (2-tailed).

**Figure 3.6.** Scatter plot of the correlation between Forest area and rainfall.

The correlation between rainfall and arable production per capita index depicts a relationship in which as rainfall decreases so does arable production per capita index and vice versa. The r of 0.268 depicts a weak association or correlation between rainfall and arable production per capita index. An R^2 of 0.072 signifies that about

7.2% of the variations in arable production can be explained only by the linear relationship between rainfall and arable production (Figure 3.7 and Table 3.2). This goes to confirm the fact that rainfall cannot be used to explain the declining trends observed in food production in the area. This is so because in the 1990s rainfall was rising in the region and at the same time food production was still in a deficit because the effects of declining forest area affect arable output more; this goes to explain why such a weak correlation exist (Epule *et al.*, 2012a; Anyamba and Tucker, 2005).

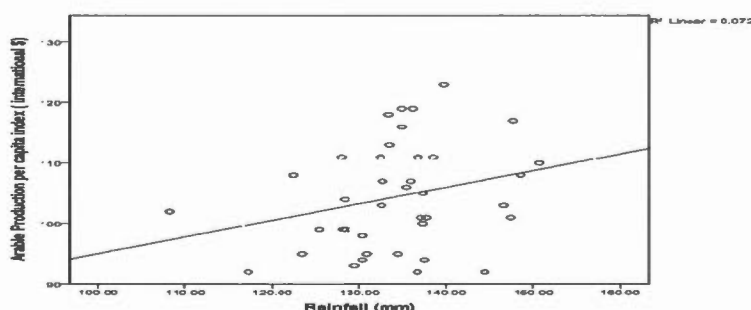


Figure 3.7. Scatter plot of the correlation between rainfall and arable production per capita index.

Scatter plots of the correlation between forest area and arable production per capita index depicts a relationship in which as forest area reduces so does arable production per capita index and vice versa. The r of 0.668 depicts a fairly moderate positive association or correlation between forest area and arable production per capita index. The R^2 of 0.446 depicts that about 44% of the variations in arable production can be explained by the linear relationship between forest area and arable production. The level of predictability of this model is ranked at slightly below average but better than in figure 3.7, this means that change in forest area accounts for changes in arable production better than rainfall does account for changes in arable production (Figure 3.8 and Table 3.2). Forest area decline affects arable production per capita by

reducing the amount of water available in the land phase of the hydrological cycle. Epule *et al.*, (2012a) argue that forest area is a more dynamic factor that affects arable production in the region more than rainfall. These views are supported by, (Hulme, 2001; Olsson and Mryka, 2008; Eklundh and Olsson, 2003).

Finally, scatter plots of the correlation between rainfall and total CO₂ emissions depicts an inverse relationship in which as rainfall reduces, CO₂ increases and vice versa. The r of -0.389 depicts a weak negative or inverse association or correlation between rainfall and total CO₂ emissions. The R^2 of 0.151 depicts that only about 15% of the variations in CO₂ emissions can be explained by the linear relationship between rainfall and forest CO₂ emissions. The relationship between rainfall and CO₂ is usually indirect as decrease rainfall only increases CO₂ by reducing forest area. Therefore, forest area is affected more by deforestation rather than by rainfall (Figure 3.9 and Table 3.2) (Epule *et al.*, 2011b; Wang and Eltahir, 2000).

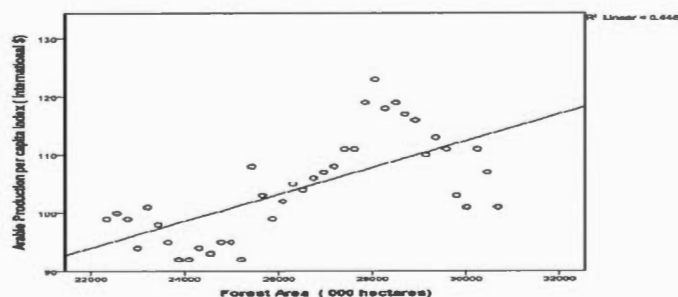


Figure 3. 8. Scatter plot of the correlation between Forest area and Arable production per capita index.

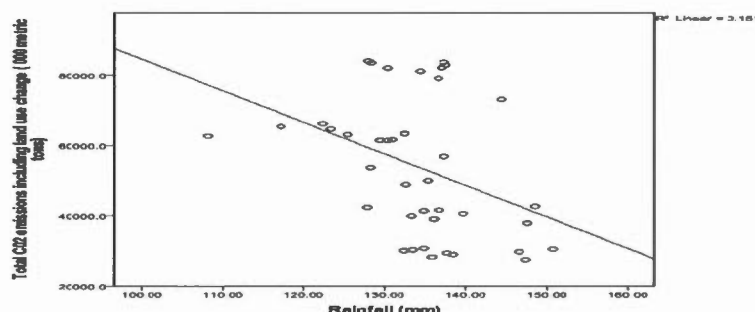


Figure 3.9. Scatter plot of the correlation between rainfall and total CO₂ emissions.

3.6. CONCLUSION

This study concludes that there is a very intricate interaction between rainfall, CO₂ emissions, forest area and arable production. However, it is even more significant to note that according to this study the most significant variable that affects CO₂ emissions in Cameroon is forest area dynamics and the most significant variable that affects arable production is forest area. This is because as forest area reduces the CO₂ in the atmosphere increases and vice versa. Also, as forest area declines, arable production also declines. There is a weaker correlation between rainfall and arable production (when compared to that between forest area and arable production) in which as rainfall reduces arable production also reduces. From the simulations, rainfall is very variable and remains a very uncertain factor that cannot explain arable production adequately as it rises in the 1990s and between 1999/2000 it declines. However, this study proposes that the use of compost fertilizers could help improve arable production in Cameroon (Epule *et al.*, 2012b). Other studies could be carried out at continental scales in Africa and other regions of the world to test these results. It is also recommended that more variables be brought into other analysis; these may include the effects of fertilizers, temperature and winds which are not considered in this study.

3.7. ACKNOWLEDGEMENTS

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3.9. APPENDIX

Table 3.3. Raw Data of the core variables under consideration

Years	Total CO ₂ emissions from forest area loss (000 metric tons)	Forest Area (thousand hectares)	Rainfall (mm)	Arable Production per capita index (international \$)
1961	26424.4	30907	139.92	97
1962	27503	30687	147.38	101
1963	28314.3	30467	135.89	107
1964	28975.6	30247	138.54	111
1965	29458.4	30027	137.78	101
1966	29771.4	29807	146.59	103
1967	30110.1	29587	132.48	111
1968	30343.4	29367	133.55	113
1969	30565.7	29147	150.73	110
1970	30780.5	28927	134.91	116
1971	37929.5	28707	147.64	117
1972	39083.9	28505	136.13	119
1973	39959	28285	133.43	118
1974	40653.2	28065	139.73	123
1975	41420.5	27845	134.91	119
1976	41674.5	27625	136.77	111
1977	42382.9	27405	127.99	111
1978	42662.6	27185	148.59	108
1979	48859.5	26965	132.7	107

1980	49981.7	26745	135.41	106
1981	53687.8	26525	128.37	104
1982	56865.6	26305	137.39	105
1983	62706.8	26085	108.21	102
1984	63152.3	25865	125.48	99
1985	63411.1	25645	132.58	103
1986	66258	25425	122.49	108
1987	65413.5	25205	117.26	92
1988	61710.8	24985	130.95	95
1989	64686.4	24765	123.45	95
1990	61490	24545	129.5	93
1991	61429.3	24325	130.41	94
1992	73131.4	24105	144.46	92
1993	79107	23885	136.7	92
1994	81111	23665	134.45	95
1995	82007.4	23445	130.41	98
1996	82137.9	23225	137.1	101
1997	82936.3	23005	137.6	94
1998	83502.9	22785	128.45	99
1999	83696.5	22565	137.37	100
2000	84105.5	22345	128.12	99

Sources. www.faostat.org, www.wri.org, www.country-profiles.geog.ox.ac.uk

CHAPTER IV

RAINFALL AND DEFORESTATION DILEMMA FOR CEREAL PRODUCTION IN THE SUDANO-SAHEL OF CAMEROON

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4.1. RÉSUMÉ

Les données de séries chronologiques indiquent que le Sahel du Cameroun a éprouvé plusieurs années de déficits dans la production de céréales. Dans la population, on attribue les tendances observées à des basses de précipitation. Les incertitudes liées au rôle des précipitations comme facteur causal principal est évident et a besoin de vérification. Pour obtenir les données, 200 questionnaires et une discussion de groupe ont été réalisés. Les études ont inclus une revue de littérature et l'analyse détaillée des images satellites selon le NDVI (*Normalized Difference Vegetation Index*) de végétation et de précipitation de la part de projet globaux de climatologie et de précipitations (GPCP). Les données obtenues à partir des questionnaires ont été analysées utilisant SPSS (statistical package for the social sciences version 19). Les résultats prouvent que la production de céréales a diminués tandis que les précipitations ont augmenté de 30-40% pendant les deux dernières décennies dans la zone d'étude. Avec une augmentation de la précipitation, la baisse observée dans la production de céréales ne peut pas être expliquée par le climat seulement. Les changements d'utilisation des terres tels que le déboisement sont de meilleures variables explicatives des tendances observées.

4.2. ABSTRACT

Time series data reveals that the Sahel of Cameroon has experienced several years of deficits in cereal production. The debate attributes the observed trends to low rainfall. Uncertainties in the debate on the role of rainfall as a principal causal factor are evident and need verification. Both field and desk studies have been used; this involved the administration of 200 questionnaires and focused group discussions. The desk studies included detailed literature review and analysis of images of the correlation between vegetation and rainfall in the entire Sahel. Also, data on the specific study area such as Normalized Difference Vegetation Index (NDVI) satellite images, NDVI time series data of vegetation, rainfall and rainfall anomalies time series data were collected from the United States Geological Survey (USGS), the Advance Very High Resolution Radiometer (AVHRR), the National Oceanic and Atmospheric Administration (NOAA) and the Kousseri-Maroua Meteorological station. The questionnaires were analysed using the SPSS to calculate the percentages and frequencies. Downscaling and generalised observation of trends were used to analyse the satellite images. The results show that cereal production has declined while rainfall has increased by 30-40% in the last decade in the study area. With an increase in rainfall, the observed decline in cereal production cannot be explained by the rainfall. A correlation between mean annual NDVI and mean yearly rainfall for the Far North region only of 0.17(17%) is obtained. This shows that for the far North region of the country there is a weak relationship between NDVI and rainfall. However, the correlation analysis used here should be treated with caution because only 15 data points were entered for both variables due to the available data and it is based on only one region of the country. An increase in the data points to about 30-35 and coverage over other regions may enhance these results. This is explained by the fact that the rising rainfall is not often sufficiently available for forest regeneration and agriculture because of high rates of deforestation. Land use change such as deforestation patterns are significant in explaining the trends in cereal output as seen in population perceptions. However, another correlation based on downscaled Sahelian data shows a very high positive correlation between greening (NDVI) and rainfall. A disparity in results observed between local and large scale studies. The main weakness of this paper is that much of the greening trends are based on NDVI which does not provide data before 1982 and should be treated with caution because in the Sahel, NDVI tracks mainly interannual variability in herbaceous vegetation.

KEYWORDS: *Sudano-Sahel, Cameroon, cereal, rainfall, deforestation*

4.3. INTRODUCTION

Climate is dynamic and changes continuously with long term cold and warm episodes. Human activities in terms of land use patterns have been linked to extreme changes in climate. Such climate variability has had lots of effects on water and agricultural resources (Molua and Lambi, 2006). In Africa, non-linear heat effects have been recorded for maize as evidenced by historical data. This means that each degree above 30⁰ C reduces final yields by 1% (Lobell *et al.*, 2011).

The Sahel is a semi-arid shrub and grassland that is a transition zone between the arid Sahara in the North and the wetter tropical zone in the south. It further stretches from the Atlantic ocean in the west to the horn of Africa in the east (around Somalia). The climate of the Sahel is marked by seasonality expressed in a long dry season and short wet season and it has a population of over 60 million people (Herrmann *et al.*, 2005; Integrated Regional Information Network (IRIN), 2010). The dry spells experienced in the Sahel in the late 20th century affected production and have been attributed to human factors such as increased deforestation, increased atmospheric aerosols and increased green house gases (GHGs), (National Oceanic and Atmospheric Administration (NOAA) and Geophysical Fluid Dynamics Laboratory (GFDL), 2007). Projections up to the 21st century illustrate that the Sahel will be drier in the future due to GHGs. If these suggestions of long term projections of temperature rise and rainfall reductions are realised, the Sahel will experience more droughts in the 21st century than in the 20th century (Intergovernmental Panel on Climate Change (IPCC), 2007). It is argued that climate change will cause a 25 % reduction in rainfall in the Sahel by 2100 (NOAA and GFDL, 2007).

As emphasized earlier, climate change can be seen as a potential big threat to the survival of humankind. This is evident as projections of climate change are however subject to uncertainties as a result of several interacting factors including, limitations in knowledge on climate change and the ongoing and ever changing debates. It has

been noted that future GHG emissions cannot be known with exact precision but an understanding of socio-economic and atmospheric processes can be used to produce a range of plausible values (IPCC, 2001a, b; IPCC, 2007). The United Nations Environment Program (UNEP), (2005) also suggest temperature changes for Africa of between 0.2^o C to 0.5^o C per decade. It is also mentioned that the interior regions of the continent stand at higher risks from adverse changes in rainfall and temperature (IPCC, 2001b; IPCC, 2007).

Global agricultural productivity decline has been blamed more on changes in rainfall for a very long time than on changes in land use patterns over the long run (Olsson, 2008). As such, the year to year variability in agricultural output has been linked to climate change (IPCC, 2001b, IPCC, 2007). Rainfall has for a long time been seen as a key driver of food security and this is logical as the role of rainfall in crop production is important. However, things are beginning to change as some of these long established views concerning the dominant role of rainfall in affecting cereal yields are currently not very tenable due to global change processes (Gregory *et al.*, 2005; Verdin *et al.*, 2005).

Today, based on observed rainfall and greening trends observed in most of the Sahel, the discourse is changing rapidly and scientists now have differing views on whether the Sahel will get wetter or drier (IRIN, 2010). The changing views on the role of climate change in the entire resource limitation debate establishes climate as a key element of uncertainty in the Sahel at the moment (Olsson, 2008). Meanwhile, cereal shortages are a reality in the Sudano-Sahelian region of Cameroon. In 1998; the World Food Program (WFP) gave some 9500 tons of food to subvert shortages in the Sudano-Sahelian part of Cameroon. This situation repeated in 2005 following drops in agricultural output (Molua and Lambi, 2006).

Based on the current uncertainty surrounding the role of Sahelian rainfall in causing persistent food shortages in the Sahel in general and in the Sudano-Sahelian region of

Cameroon in particular, this study aims at verifying the relative contributions of forest area dynamics and rainfall on cereal production.

4.4. THE STUDY AREA

The study area extends from Touroua, Garoua, and Maroua through Kousseri to the Lake Chad basin and will be referred to in this paper as the Sudano-Sahel of Cameroon. It has a short rainy season (July to October) and a long dry season. Annual rainfall ranges from about 900 mm in the Maroua area to 500 mm around Kousseri and 400 mm around Lake Chad (Molua, 2006; Maroua, 2011). Maroua which is the capital of the extreme North region and part of the Sahel of Cameroon has a population of 2,553,389 inhabitants as of the 2005 population census. The total surface area involved here is 34,263 km² with a population density of 40-74.52 inhabitants per km² (Civil cabinet of the presidency of the Republic, 2011). The Sahel in general has an area of 3,630,000 Km², this implies that the portion of Cameroon under study is about 10% the size of the entire Sahel (IRIN, 2010). In general, there is great similarity between the different parts of the Sahel in terms of the trends of the observed parameters such as rainfall, temperature, agricultural systems, cultures and problems faced by the inhabitants *inter alia* though slight spatial variations might exist in scale and magnitude (figure 4.1) (Herrmann *et al.*, 2005; Olsson *et al.*, 2005).

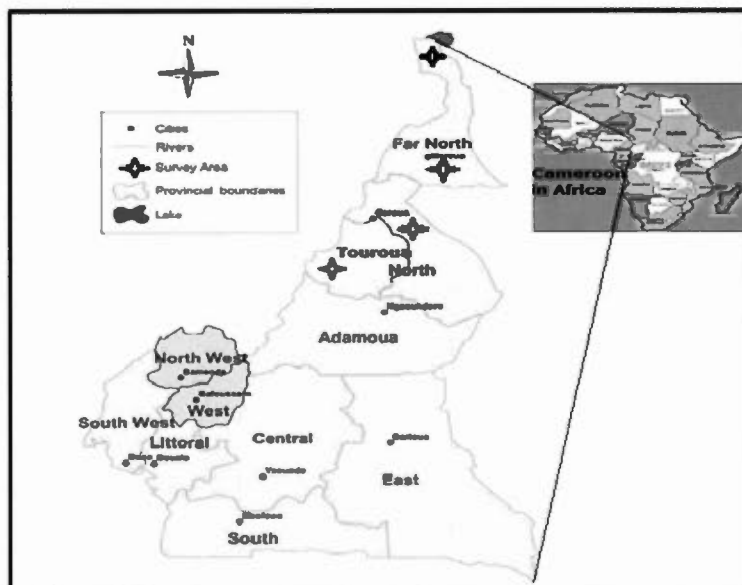


Figure 4.1. Map showing the study area in Cameroon and in the Sahel of Africa.

Source: Modified from Fontem *et al.*, (2005).

4.5. METHODOLOGY

Three principal methods of data collection and analysis were used. Firstly, 200 questionnaires were administered to 200 household heads and grain farmers in Touroua, Garoua, Maroua and Kousseri. 50 questionnaires were administered in each region, one focus group discussion (FGD) composed of 15 respondents was held in Touroua with household heads, farmers and an authority from the ministry of agriculture. The choice of who was included in the discussion based handed over to the village committee of elders who selected the participants based on their past experience with environmental campaigns in their community. All those invited attended. During the discussions, the researchers and research assistants explained all the objectives of the project to the participants. Clarifications were made in cases where the participants were not clear about some of the themes. This was followed by discussions of the key questions which centered around: the participants' perceptions of the status of deforestation and rainfall in their area as well as their views on

whether their grain yields were rising or declining and whether it was rainfall or deforestation that was at the centre of the problem. The topics were introduced by the researchers progressively and the perceptions of the participants recorded accordingly.

Kousseri has a population of about 89,123 inhabitants and has a total surface area of about 14km² (Civil cabinet of the presidency of the Republic, 2011; Google maps, 2011). These areas are of strategic importance because they are essentially inhabited by grain farmers who have a better perception of the problems confronting agriculture in this zone. The objective here was to explore the perceptions of the inhabitants on the contributions of rainfall and land use change (deforestation) to agricultural yields. The main population sampling was through the random sampling method at household level (Williman, 2006; Bryman, 2004).

Furthermore, time series data on cereal production trends in the study area between 1975 and 2005 were obtained from the Garoua cereal office. In addition, other secondary data sources consulted included literature that has covered most of the recent climate polemics with respect to agriculture in the Sahel in general and the Sudano-Sahelian region of Cameroon in Particular. The sources consulted present information on the relationship between vegetation (NDVI) and rainfall in the Sahel (figure 4.5, 4.6 and 4.7) (Herrmann *et al.*, 2008; Olsson and Mryka, 2008).

The NDVI is a ratio of the near infrared and red spectral reflections and it is calculated as $(NIR - VIS) / (NIR + VIS)$. Where: VIS and NIR stand for the spectral reflectance measurements acquired in the visible red and near infrared regions of the electromagnetic spectrum respectively. NDVI has served as a proxy for mapping rainfall variations (Tucker and Nicholson, 1999; Herrmann *et al.*, 2008). NDVI data spanning the period 1988 to 2002 for parts of the Adamawa region, North and Far north were obtained from the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) space programs.

Other NDVI satellite images for the study area were obtained from the United States Geological Survey (USGS). NDVI data for the entire Sahel was pulled from the following published articles: Herrmann *et al.*, 2005; Olsson and Mryka, 2008; Eklundh and Olsson, 2003. The average annual rainfall data for the Far north region of Cameroon alone and the annual rainfall anomalies data for all the three northern regions were collected from the Kousseri-Maroua Meteorological station.

The questionnaires were analyzed with the Statistical Package for the Social Sciences (SPSS) version 19 from which frequencies, percentages and the correlation between NDVI and rainfall for the Far north region was estimated. The FGD was analysed through verbatim transcriptions of the opinions of the participations. The NDVI data from published articles was analysed by downscaling from the observations of general Sahelian NDVI and rainfall to observations of the specific situation in the Sudano-Sahel of Cameroon. This zone is represented by the region in and around the rectangle on figure 4.7. For the NDVI data from AVHRR and NOAA and the annual rainfall data, correlation analysis and trend graphs were used. To smoothen out short term fluctuations in the cereal yield data and provide indications of overall trends in the data, three period moving averages were applied to the data using the SPSS software package. The advantages of the three period moving averages go beyond smoothening and reducing variations in the data to facilitating the analysis of large time series data and to see the gaps between simulated and actual trends (Valleman, 1981; Hseih, 1991). Also, averages for each five year period were calculated for the cereal output data to easy representation on the bar graphs. Correlations analysis was performed on the rainfall and NDVI data for the Far North region. The time series data on cereal yields was further analyzed by subtracting the actual production from the projected production. In this way, the deficits for the different years were obtained. The equation derived by this study and used to carry out the calculations is as follows:

$D_{iy} = PP_{iy} - AP_{iy}$ Where: D_{iy} is the deficit for the i th year, PP_{iy} is the projected production for the i th year; AP_{iy} is the actual production for the i th year.

4.6. RESULTS

4.6.1. Cereal output trends and population perceptions of causes of observed trends

Cereal production decline was observed for the period analysed (1975-2005). As seen on table 4.1, there were 20 years during which deficits in production were observed because the projected production needs were not attained. Each year from 1993 to 2005, showed a production deficit based on the actual production data versus the projected production data (see Table 4.1, figure 4.3 and figure 4.4). However, data has been compressed through a calculation of the three period moving averages and averages which shows that the simulated and actual data are not very variable from each other (figure 4.3, figure 4.4). For these averages, the period of deficit begins from the 1990-1994 average with a deficit of 70,000 tons, 1995-1999 average with a deficit of 150,000 tons, and the 2000-2005 average with a deficit of 190,000 tons (figure 4.4 and table 4.1).

Based on the analysis of the questionnaires, this study has found out that from the 200 respondents, 124 are farmers, 52 are cattle rearers, 14 are rice vendors and 10 are teachers (see Table 4.2). The implication of this is that the results are fairly reliable because they represent responses from key stakeholders who are most involved in the cultivation of cereals.

Furthermore, 72 of these respondents attribute cereal declines to climate change while 121 think anthropogenic factors are responsible. A detailed analysis of the anthropogenic factors shows that 5 respondents have the perception that vertical slope cultivation is responsible for cereal declines, 7 respondents have the perception that cattle rearing is responsible for cereal decline, 25 respondents have the perception that population growth is responsible for cereal decline, 66 respondents have the perception that deforestation is responsible for cereal decline and 18 respondents have the perception that lack of capital and technology are responsible for cereal decline

while 7 respondents have no idea (figure 4.2). If all the non-climate factors are added, we obtain 121 respondents who attribute the declines to anthropogenic factors. This underscores the declining influence of rainfall. 172 of the respondents think cereal output is declining, 20 think it is increasing while 8 think it is stationary (Table 4.3. and Table 4.4.).

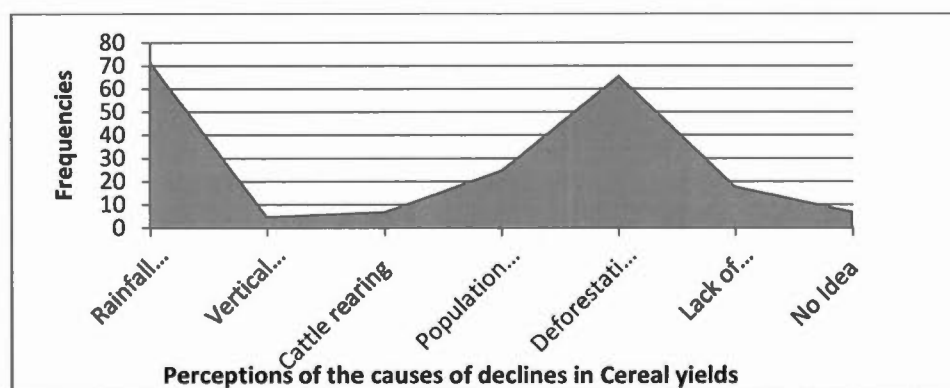


Figure 4.2. Perceptions of the causes of declines in cereal yields.

Table 4.1. Trends in cereal output and quantity of cereal needed from 1975 to 2005 for the Sudano-Sahel of Cameroon

Years	Total Production (Tons) Actual production	Quantity Needed (Tons) Projected production	Deficit or Surplus (Tons) $D_{iy} = PP_{iy} - AP_{iy}$
1975/76	253 683	229 161	+ 24 522
1976/77	267 458	235 190	+ 32 268
1977/78	230 092	241 365	- 11 273
1978/79	289 485	247 722	+ 41 763
1979/80	251 292	254 243	- 2951
1980/81	262 841	260 928	+ 1913

1981/82	207 341	267 793	- 60 452
1982/83	381 153	274 840	+ 106 313
1983/84	223 298	282 066	- 58 768
1984/85	127 041	289 474	- 162 433
1985/86	364 532	297 112	+ 67 420
1986/87	450 395	304 799	+ 145 596
1987/88	424 406	312 814	- 111 592
1988/89	292 803	321 043	- 28 240
1989/90	359 528	329 486	+ 30 042
1990/91	245 992	338 158	- 92 166
1991/92	402 234	347 044	+ 55 190
1992/93	432 517	356 176	+ 67 341
1993/94	180 200	365 538	- 185 338
1994/95	180 000	367 500	- 187 500
1995/96	241 500	445 477	- 203 977
1996/97	355 000	468 000	-113 000
1997/98	384 000	491 256	- 107 256
1998/99	300 857	491 332	- 190 475
1999/00	329 372	495 345	- 165973
2000/01	325 321	496 221	- 170 900
2001/02	323 022	498 010	- 174 988
2002/03	320 213	498 376	- 178163
2003/04	318 987	498 518	- 179531
2004/05	315 025	499 259	- 184234

Total production represents the actual quantity of cereals produced while projected production is the anticipated production target set by the government. The production deficits or surplus are the differences between actual production and anticipated production. Of the 30 years for which data was available, deficits are recorded for 20 years as indicated by the minus signs from 1993 to 2005.

Source: Calculated based on estimates from cereal office Garoua and ministry of Agriculture and Rural Development, (2009).

From the FGDs most of the respondents believe that the key problem with their yields has to do with their current farming systems, cattle rearing, population growth capital technology and deforestation. These views are also tightly consistent with the views of the authorities in the ministry of agriculture who hold that declining cereal yields are due to deforestation and unsustainable farming methods such as cultivation on slopes in the Mandara mountain region rather than rainfall which is reported to be rising (see Table 4.3 and 4.4). However, among the anthropogenic factors, the most important causes of cereal decline according to respondents are deforestation, population growth and capital technology (figure 4.2).

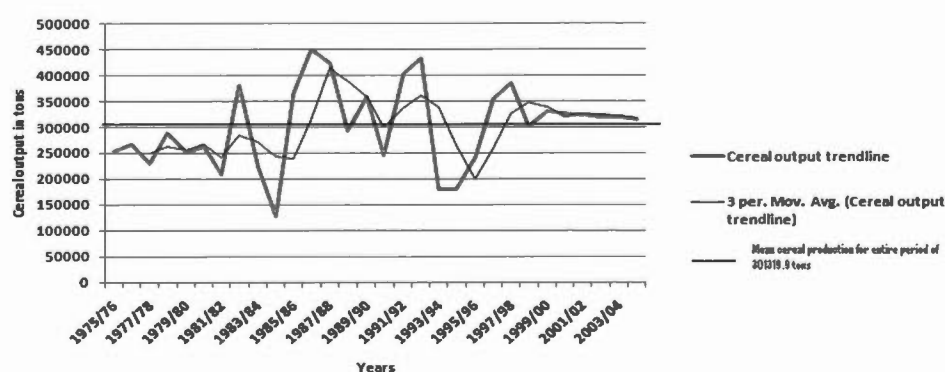


Figure 4.3. Trends in cereal production, average production and 3 period moving averages. These curves are based on the trends of the actual production over time and

not the deficits. In general, even when the curve is smoothened there are several periods below the mean.

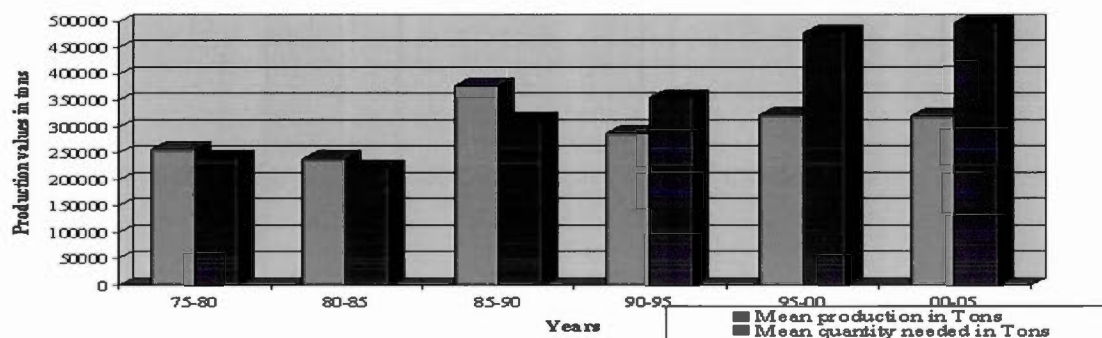


Figure 4.4. Mean trends of quantity of cereal produced and quantity needed in the Sudano-Sahel of Cameroon. The observations are from 1975 to 2005 and are based on the averages. Persistent deficits are obtained from 1990 to 2005.

Table 4.2. Distribution of professions in the study area

Professions	Number of Respondents
Farmer	124
Vegetable Vendor	0
Rice Vendor	14
Hunter	0
Teacher	10
Cattle rearer	52
Others, Specify here,	0

Table shows that a majority of the 200 respondents consulted are farmers. This shows that the perceptions are generally reliable because these farmers are partly responsible for the cultivation of all the cereal in the region.

Table 4.3. Perceptions of climate change as the main causes of cereal decline

Yes	No	No Idea

72	121	7
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Table shows populations perception of rainfall as main cause of cereal decline. Of the 200 respondents 121 report that rainfall variations are not responsible while 72 think decline in rainfall is responsible and 7 respondents have no idea. Table 4.4 and Figure 4.2 shows the subdivisions.

Table 4.4. Population perceptions of the causes of cereal decline

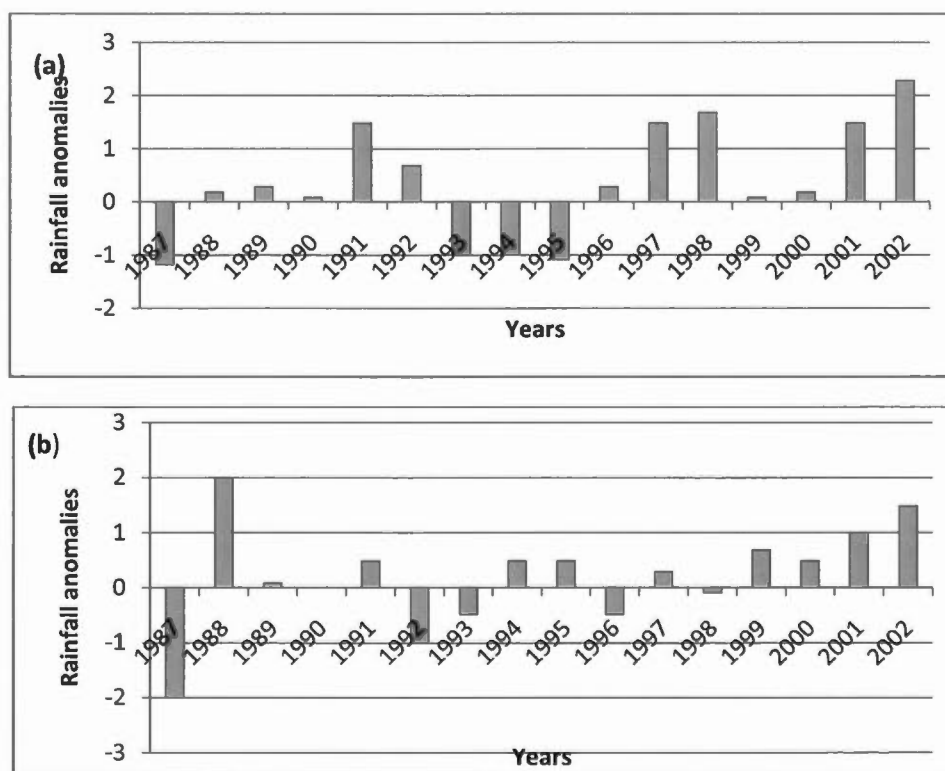
Causes of cereal decline	Number of Respondents
Rainfall(Climate Change)	72
Vertical slope farming	5
Cattle rearing	7
Population growth	25
Deforestation	66
Capital, technology	18
No idea	7

The table further shows the detailed results of population perceptions of the causes of cereal decline. 72 respondents attribute it to rainfall decline while 7 have no idea. The remaining 121 respondents think rainfall is not the cause and attribute the trends to other factors as follows: vertical slope farming 5, cattle rearing 7, population growth 25, deforestation 66 and capital technology 18.

In the same way, overall trends in monthly rainfall for the Sahel from 1982-2003 based on published estimates that originate from the GPCP express percentage increase in rainfall. This is confirmed when we observe that there has been a positive change in rainfall in the Sahel in general and the Sahel of Cameroon in particular (see figure 4.5). When the overall Sahelian situation is downscaled, it can be observed that a percentage increase in rainfall of about 20-40 % has been recorded for the study area (Herrmann *et al.*, 2005). Between 2005 and 2010 and based on a bird's eye view,

a progressive expansion of the extent of the vegetation in the Sahel of Cameroon is also observed (figure 4.6).

A correlation between mean annual NDVI and mean yearly rainfall for the Far North region only of 0.17(17%) is obtained. This shows that for the Far north region of the country there is a weak relationship between NDVI and rainfall, a significant departure from the close to 85% correlation observed at the level of Sahelian based data. However, the correlation analysis used here should be treated with caution because only 15 data points were entered for both variables due to the available data and it is based on only one region of the country. An increase in the data points to about 30-35 and coverage over other regions may enhance these results.



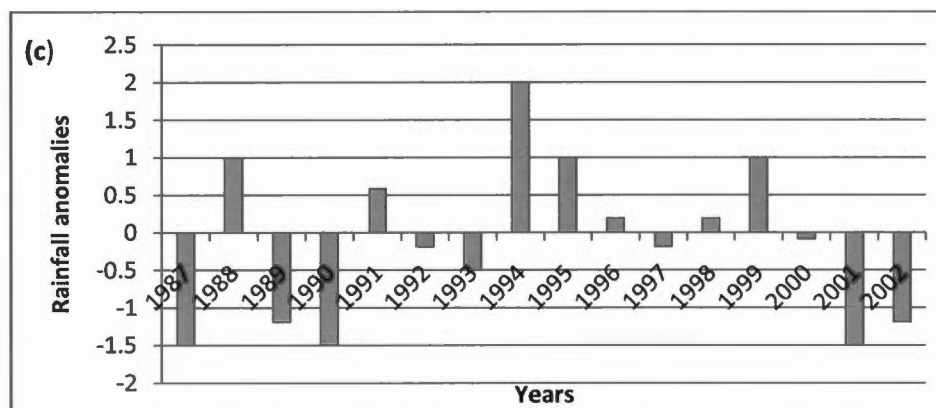


Figure 4.5. Rainfall anomalies at three regions of Cameroon, (a) the Far North (10-13°N), (b) the North (8-9°N) and (c) Adamawa (6-7°N).

Source: Based on Data from the Kousseri-Maroua Meteorological station.

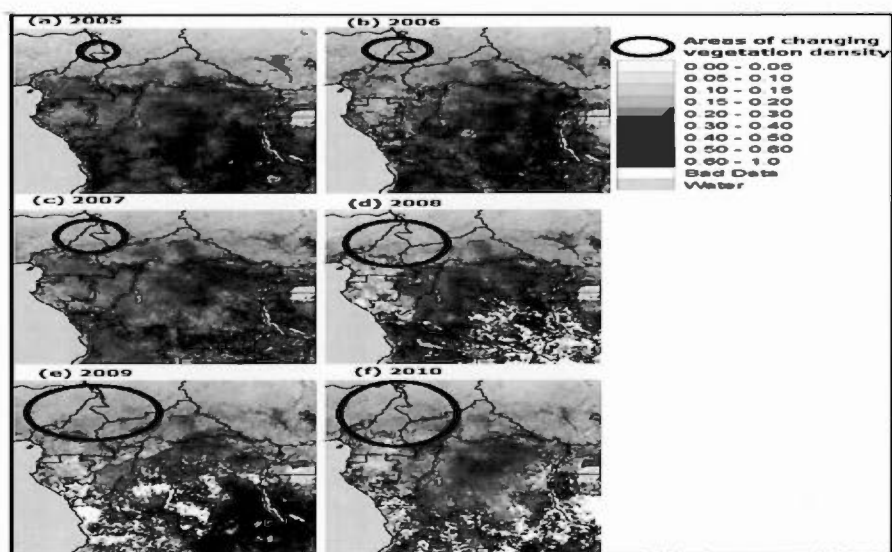


Figure 4.6. Overall bird's eye view trends in annual NDVI between 2005 and 2010 for the Northern regions of Cameroon.

Source: Data pulled from United States Geological Survey.

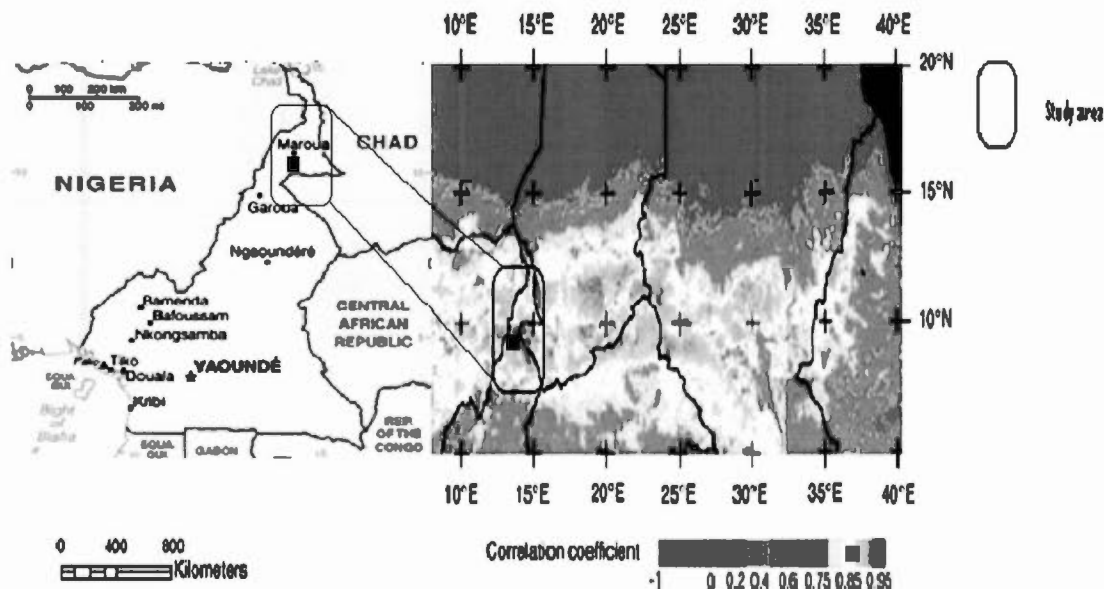


Figure 4.7. Linear correlations of monthly NDVI with 3-monthly cumulative rainfall based on GPCP estimates for the period 1982-2031. As rainfall increases so too does greening increase in the Sahel. In the case of Cameroon, a linear correlation of 0.85 (see black squares) is recorded for the region within and around the rectangle following downscaling from the large scale data.

Source: Modified and downscaled from Herrmann *et al.*, (2005) and Cameroon Today (www.cameroon-today.com).

To further support the argument that rainfall in the Sahel of Cameroon is increasing; linear correlations of the monthly NDVI with three monthly cumulative rainfalls based on GPCP estimates have been used. If we downscale the observations we observe that for the region which stands for the Sahel of Cameroon, a correlation coefficient of about 0.85 is obtained. This means there is a very strong positive correlation between vegetation or greenness and rainfall (see figure 4.7). The high correlation of 85% between NDVI and rainfall from this larger regional scale data is different from the very low correlation of 17% between NDVI and rainfall from the locally based data from the Far North region. The question that has to be answered is,

why then is food production declining when rainfall is rising? The answer is found in the anthropogenic factors mentioned earlier. Local level time series and NDVI images for the north of Cameroon also shows relatively higher than average NDVI over time. For the trends in local NDVI for the Far North, North and Adamawa regions, we observe that as one transitions from north to south, the maximum NDVI increases indicating rising rainfall and better water management strategies (figure 4.8). Also, the disparity observed in the local based correction in the Far North region (17%) and the entire Sahel (85%) could be explained by the fact that larger scale studies on which the entire Sahelian based study is based may not often be able to reflect local realities as such large scale studies tend to underestimate local realities (Giannini *et al.*, 2008).

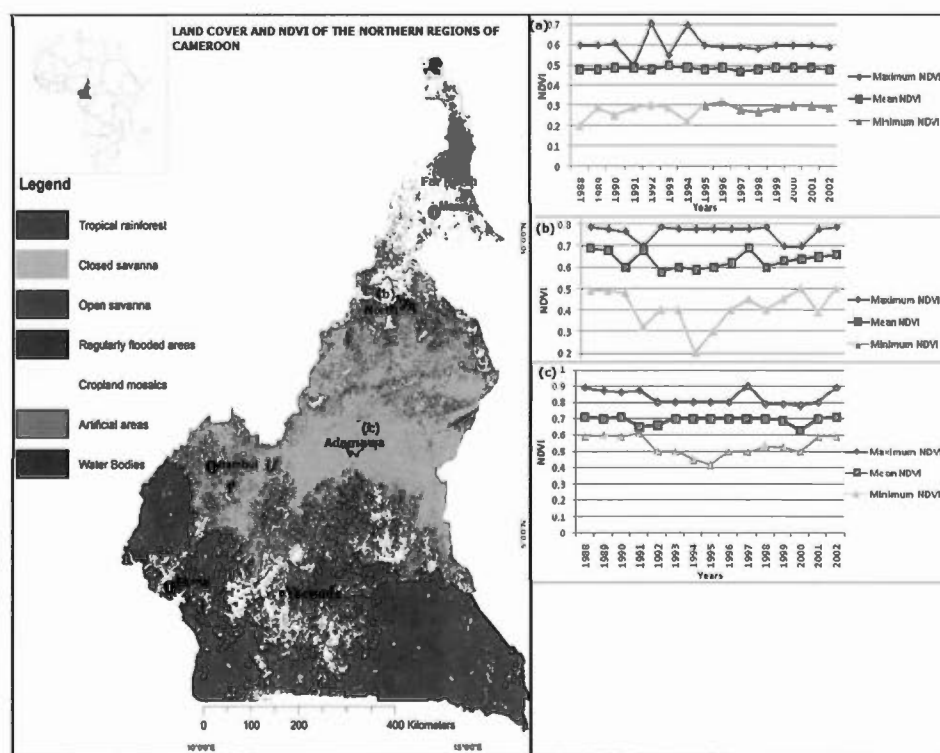


Figure 4.8. Variation in vegetation and NDVI with time along Latitude (a) 13° N - 12° N and Longitude 14° E - 15.5° E or Extreme/Far north region (b) 10° N - 9° N and

Longitude 12° E 15.5°E or the North region, (c) 7° N - 6° N and Longitude 11° E-16°E of the Adamawa region of Cameroon.

Source: Based on data from AVHRR and NOAA.

4.7. DISCUSSION

4.7.1. Sahelian Greening and rainfall versus land use patterns

One would expect a conclusion that declining cereal output is strongly linked to declining rainfall in the Sahel. However, a new component in the debate seems to have been opened. The Sahel has experienced relative greening during the period 1990-2003 caused mainly by increase in rainfall (Olsson and Mryka, 2008; Eklundh and Olsson, 2003; Hulme, 2001). Nicholson (2005) remarks that the increased rainfall hypothesis is evident when he argues that most of the central and southern parts of the Sahel experienced increase rainfall. If this is true, then we will have to subscribe to other factors in an attempt to explain the current declines in cereal production in the Sahel of Cameroon. This view point looks tenable since the Sahel is a zone of sharp seasonal contrast with fluctuations in rainfall at inter-annual and decadal scales. This makes the Sahel to be considered further as a region of climatic variability. As such, the current increases in Sahelian rainfall do not come with lots of doubt (Hulme, 2001).

In the specific case of the Sahel of Cameroon it is observed that rainfall is increasing as well. However, the correlation between rainfall and NDVI in the Far North region is very low (17%) when compared to that obtained by downscaling general Sahelian data (0.85%) for the same region in Cameroon. The correlation between rainfall and NDVI for Cameroon should be interpreted with caution for the following reasons: 1. It was based on only 15 data points of rainfall and NDVI due to data availability and 2. It was based only on the Far North region. However, Giannini *et al.*, (2008) argued that the increase correlation between rainfall and greening reported by the larger scale

studies that also cover parts of Cameroon should not be entirely assumed as representative of what obtains at local scales such as in the Sahel of Cameroon. To these authors more affluent communities are more able to carry out land and water management which can enhance greening while adjacent poor communities do not often have such capacities. They therefore recommend studies based on data that represent local realities of specific communities as is the case with this study. Also, the disparity observed in the local based correction in the Far North region (17%) and the entire Sahel (85%) could be explained by the fact that larger scale studies on which the entire Sahelian based study is based may not often be able to reflect local realities as such large scale studies tend to underestimate local realities (Giannini *et al.*, 2008).

Though the Sahel experienced declining rainfall in the 1950s-1980s, changing trends of increase rainfall were observed from 1985 (Olsson and Mryka, 2008; Wang *et al.*, 2000). The effect of declining rainfall in the Sahel of Cameroon in particular and Africa in general is that the Sahel is a hunger threatened region. Projections show that by 2020, food shortages would have reduced in most developing countries but the Sahel will still be facing problems with food shortages due to inappropriate land uses such as deforestation, over cultivation, cattle stock rearing and rapid population growth (IFAD, 2001; Olsson and Mryka, 2008). In fact, population growth in itself has recently been analysed as a major cause of deforestation in Cameroon (Epule *et al.*, 2011). Even if cereal outputs will rise in sub-Saharan Africa, it is however quite possible that due to an increased population, the growth in production will be worthless and the amount of malnourished children will keep on a pessimistic turn towards 2020 (IFAD, 2001). On a global scale, it is also argued that global maize and wheat production had declined between 1980 and 2008. The latter decline is said to be influenced more by temperature than changes in precipitation. This again underscores the fact that the influence of precipitation on the decline in grain yields is not as significant as other factors, at least for now (Lobell *et al.*, 2011).

The question now is, are there any other studies that support the correlations between the observed rainfall and greening? Increased greenness correlates perfectly at a coarse scale with increase in rainfall in the Sahel. Studies have argued that the areas of increased greenness are same as those of increase rainfall, though these same areas have experienced declines in cereal yields, a view supported by the following authors (Herrmann *et al.*, 2005; Olsson *et al.*, 2005; Zeng *et al.*, 1999; Anyamba and Tucker, 2005).

Based on the trends described above, one would expect that if there is an increase in rainfall in the Sahel in general and the Sudano-Sahelian zone of Cameroon in particular there should be an increase in food production. Paradoxically, this has not been the case, as seen in the cereal yields for the Sahel of Cameroon. In the past, the occurrence of droughts played a strong role in declining food stocks in the region (Caldwell, 1977). In the Sahel, only Burkina Faso and Mali experienced increased production of millet (kg/capita) of 55% and 35% respectively since 1980 (Olsson and Mryka, 2008). The facts that mean actual cereal production exceeded mean projected cereal production in most of the 1990s (figure 4.4) is consistent with the rising rainfall observed in the 1990s. Lobell *et al.*, (2011) argue that climate remains only one likely factor that can shape the past and future of food production and it is of great importance to assess other factors affecting food production. As such, the observed declines in the Sahel could be explained in line with the factors that the respondents presented above that include deforestation, population growth and capital technology inter alia. In fact, it has been discussed that agricultural production has declined in Africa due mainly to land use and cover change (Ewert *et al.*, 2005; Zhao *et al.*, 2006). Land cover changes through deforestation have repercussions on food yields and this can be linked to over grazing and population pressure on dry lands (Lambin *et al.*, 2000). Stephenne *et al.*, (2001) also support the above hypothesis when they argue that land cover changes through anthropogenic deforestation, cattle rearing and population growth are responsible for grain declines in the Sahel. Bala *et*

al., (2000) and Epule *et al.*, (2011) argue further that population growth is at the centre of rapid land use change or deforestation which affects agricultural output. LeBlanc *et al.*, (1997) go further by analysing that land use change through deforestation brings about water scarcity, the effects of which are often reflected in low grain output. Therefore, deforestation for example increases water scarcity, cereal output drops because the increase in rainfall is not entirely available for agriculture due to unsustainable systems of land usage that cause water scarcity. It can be said that, when trees are destroyed through deforestation, cattle rearing and a nexus of unsustainable methods of cultivation, the water cycle is hampered and our global, regional, national and catchment area scale agricultural systems will lack sufficient water for survival (Lobell *et al.*, 2011; Epule *et al.*, 2011; Zhao *et al.*, 2006). It is therefore a problem of water management at the land phase of the hydrological cycle and not a problem of declining rainfall.

4.8. CONCLUSIONS

Observed trends of declining cereal yields in the Sudano-Sahelian region of Cameroon cannot be explained by the observed trends of increasing greening and rainfall in most of the Sahel in general and that of Cameroon in particular. Potential explanations of the declines in cereal yields could be land use systems as seen in most of the literature and data from this work. Olsson *et al.*, (2005) argue that the fact that millet yields and increase in vegetation and rainfall are found to be unrelated supports this conclusion. The observations here set in a potential for better land use management since rainfall is already increasing. It would therefore be of great importance for researchers to uncover the influence of land use systems on food production in particular and environmental degradation in general in the Sahel of Cameroon and other parts of Africa. Most studies have this far not been able to establish the link between current climate trends and food production in the Sahel of Cameroon, a major aim of this study. It would also be of great interest to uncover the repercussions of different land uses on the environment and the triggers behind the

deforestation at scales less than or greater than national to be able to set a better platform for mitigation.

4.9. ACKNOWLEDGEMENTS

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CHAPTER V

POVERTY AND GENDER ORIENTED VULNERABILITIES TO FOOD AND WATER SCARCITY IN TOUROUA, CAMEROON

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5.1. RÉSUMÉ

Cette étude analyse la vulnérabilité de différents groupes d'individus selon le genre et le revenu à la baisse de nourriture et au manque d'eau provoqués par le déboisement et basés sur les perceptions de populations. Les données ont été obtenues par l'administration aléatoire de 200 questionnaires dans le site d'étude. Les données ont été analysées utilisant SPSS (Statistical package for the social sciences, version 19) dans laquelle la corrélation de Pearson a été employée. Les résultats prouvent qu'il y a des relations inverses entre les niveaux de revenu et le nombre de répondants et leur perceptions à l'accès limité à la nourriture et à l'eau. Ceci implique que, quand les revenus sont bas, le nombre de répondants avec des perceptions d'accès limité à la nourriture et l'eau est haut et vice versa. En ce qui concerne le genre, nous observons de la traçage de données que les femmes sont plus vulnérables aux pénuries alimentaires et d'eau.

5.2. ABSTRACT

This paper analyses the vulnerability of different income groups and gender to food and water shortages caused by deforestation and based on population perceptions. Data were obtained through the random administration of 200 questionnaires in the study site. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 19 in which Pearson correlation, frequencies and percentages were calculated. The results show that there is an inverse relationship between income levels and the number of respondents with perceptions of limited access to food and water. This implies that, when incomes are low, the number of respondents with perceptions of limited access to food and water is high and vice versa. As concerns gender, we observe from the data plottings that women are more vulnerable to water and food shortages. The main weakness of this study is that it uses mainly incomes levels to reflect poverty levels whereas in real life there are many other indicators of poverty.

Keywords: vulnerability, food, water, income levels, gender, Pearson correlation

5.3. INTRODUCTION

Deforestation has repercussions on our environmental systems and it is responsible for ecological instability and long run social and economic development problems (Mertens and Lambin, 1997). In addition, it has been proven that food and water shortages in the north of Cameroon are mainly caused by deforestation and not rainfall (Epule *et al.*, 2012). In the same way, Misselhorn, (2005) supports these views when he argues that rainfall is only seen as a reinforcing factor when food shortages are concerned. Forests are therefore seen as systems that depict aspects of the interactions between the environmental, economic and socio-cultural sub-systems (Armenteras *et al.*, 2010). There is a growing debate that tropical deforestation is increasingly contributing to the global carbon stock, reduced agricultural output, adversely affecting discharge in rivers to name but these (Armenteras *et al.*, 2010; Epule *et al.*, 2012).

The causes of wide scale deforestation have been analyzed in different ways. An earlier study used remote sensing to digitalize the landscape that is lost in Cameroon (Mertens and Lambin, 1997) while others have simply described the causes of deforestation without scaling the relative contribution of the various factors (Carr *et al.*, 2006; Vanclay, 1993; Zhao *et al.*, 2006). However, more recently, a study that fitted a regression model has shown that population and arable production are pivotal variables causing deforestation in Cameroon (Epule *et al.*, 2011).

In sub-Saharan Africa in general and Cameroon in particular, the ability of communities to adapt to the effects of deforestation stated above varies with the wealth status and the gender of the people involved (Misselhorn, 2005; IPCC, 2007; Skeggs, 1997). The variation in the ability to adapt between respondents in different income classes and gender brings in the notion of vulnerability. When there is deforestation the soil texture becomes weakened and this reduces soil moisture which affects water supply and food production. This is evident because reduced soil

moisture will always have a net effect on crops since they will not have sufficient water for growth. Both food and water supply shortages will create elements of vulnerability to segments of the population that cannot easily adapt due to poverty as well as to the roles that are traditionally attached to different gender in domestic resources management (Cutter *et al.*, 2003; Cutter *et al.*, 2000). In general, it is not clear who between males and females and the rich and poor are more vulnerable to food and water scarcity in most African communities in general and in Cameroon in particular because both males and females, rich and poor are involved in the use and consumption of water and food in the study site, a key issue this study wishes to investigate (Blaikie *et al.*, 1994; Enarson and Morrow, 1998). Shortages in these resources will mean covering longer distances to fetch water, fetching unreliable water and working extra hard on the farms to produce very little yields (Figure 5.1) (Skeggs, 1997).

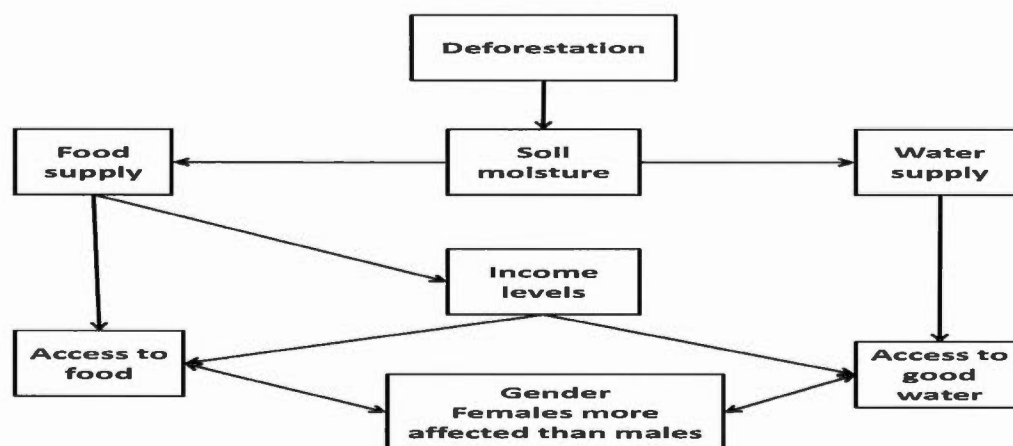


Figure 5.1. A schematic representation of the interconnections between gender and income levels on the one hand and access to food and water on the other hand.

Many definitions of the word vulnerability have been presented and the discrepancies inherent in the definitions are as a result of the differences in epistemological concentrations (human ecology, political ecology, spatial analysis and seismic issues)

(Cutter, 1996). However, some scholars have defined vulnerability as the extent to which various classes in society are differentially at risk (Susman *et al.*, 1984). Furthermore, others argue that it has three connotations which are: it refers to a consequence such as famine rather than a cause such as drought; it may include an adverse effect such as declines in maize yields; households being vulnerable to hunger and water scarcity; in relative terms it may mean the differences within socio-economic or income groups or regions in adapting to food and water shortages (Downing, 1999). Furthermore, the lack of access to resources has been described by some authors as material or economic vulnerability (Aysan, 1993; Alcantara, 2002). A hazard could include famine, drought, floods, and seismic activities *inter alia*. Vulnerability is a vital concept in hazard studies as it is central in the development of various methods of mitigation. Vulnerability is now a major indicator used by experts in curbing environmental degradation, population growth problems, poverty and development (Cuny, 1983). The latter establishes the importance of this area of study. However, in the context of Cameroon in general and Touroua in particular, this study comes in timely because much of the work on vulnerability in Cameroon has been on the aspects of vulnerability to climate change, mitigation and adaptations (IPCC, 2007; Gbeibouo *et al.*, 2010). To the best of our knowledge, this is the first study that uses the methods specified in the methodology below and data from population perceptions to analyze the vulnerability of populations to food and water shortages caused by deforestation. The fact that deforestation or land use change is at the centre of the observed food and water crisis in the region is not questionable as this has been established by Epule *et al.*, (2012) for the Sahel of Cameroon and Olsson and Mryka, (2008), Stephenne and Lambin, (2001) for the entire Sahel.

The perspectives presented above cut deeply into and beyond the scope of this paper. Just as defined, this study aims at verifying through population perceptions the extent to which, poverty levels (income levels) and different gender are differentially susceptible to famine (food shortages) and water scarcity caused by deforestation.

5.4. STUDY AREA AND METHODOLOGY

5.4.1. Study Area

Touroua is a village in the north region of Cameroon (Figure 5.2). It is some 52.4 km from Garoua the Capital of the north region of Cameroon. It is located on latitude 9.08333° north of the equator and longitude 12.9667° east of the prime meridian. The village, like most places in the north region of Cameroon, has a Sudano-Sahelian climate with annual rainfall totaling about 900 mm (Dounias *et al.*, 2002). The north region of Cameroon is experiencing high rates of deforestation linked principally to high rates of population growth due to immigration from the Far north region. The north region has a rate of immigration of 5.1 % which is much higher than the 3.2 % that obtains at the national level; this depicts the link between population and deforestation (Njiti and Sharpe, 1994; Epule *et al.*, 2011). Touroua was selected because several micro-scale tree planting projects had taken place there and some had failed while some were considered a success, a subject for another study. The aim however for this current study is to analyze aspects of vulnerability already described in detail above.

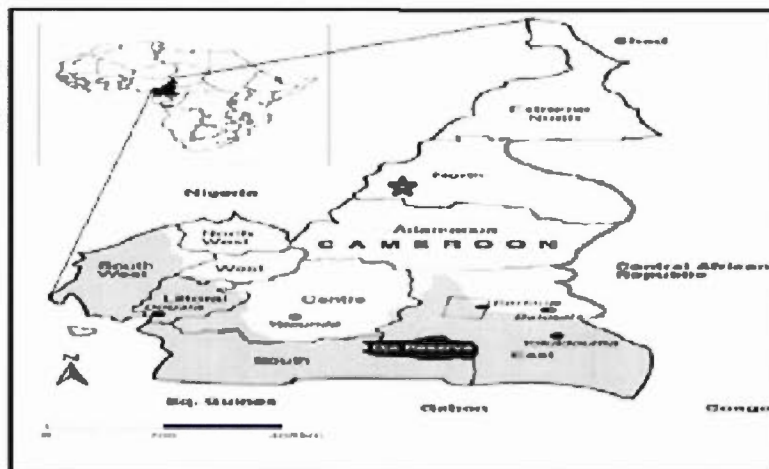


Figure 5. 2. Map of the North Region of Cameroon locating Touroua with a black star. Touroua is some 52.4 km² from Garoua the capital of the North Region.

Source: Modified from Mertens and Lambin, (2000) and Epule *et al.*, (2011).

5.4.2. Data Collection

One focus group discussion (FGD) was held with household heads, tree growers, cattle herders, farmers, traders and teachers of the local primary school. The main objectives of this 15 man FGD was to assess the respondents' opinions on: 1. problems of access to food and water due to deforestation, 2. to discuss reasons why a given gender and income level may be perceived as more vulnerable than another. A total of 200 questionnaires were administered to household heads; 100 questionnaires to respondents in the *market square* reforestation project and another 100 questionnaires to the *outdoor mosque* reforestation project. Only respondents of age 18 years and above were contacted from among household heads, tree growers, cattle herders, farmers, traders and teachers. The questionnaires were designed and structured to meet the objectives of this study and the method of administering the questionnaires was random as specified by (Williman, 2006; Bryman, 2004).

5.4.3. Data Analysis

The FGDs were analyzed using verbatim transcription. The questionnaires were coded using the unique identifiers. This was done on two excel work sheets representing the *market square* and the *outdoor mosque* sites. The unique identifiers were set vertically from row three columns A downwards and in each case the unique identifiers ranged from 001-100 and they represent the IDs of the questionnaires. The key questions were: 1. what is your profession? 2. what is your gender? 3. do you have problems of access to food and water? 4. In what level of income do you belong? Column headers or question IDs were used (A, B, C and D for the four questions respectively) and they were set from row two and column B running horizontally. The specific responses were further coded based on the number of males coded as A1, number of females coded as A2, number of males with limited access to food and water due to deforestation coded as B1, the number of females with limited access to food and water due to deforestation coded as B2 and their respective income levels coded as C1, C2, C3, C4, C5 and C6 for the < 20 000 cfaf, 20 000-40 000 cfaf,

41 000-60 000 cfaf, 61 000-80 000 cfaf, 81000-100 000 cfaf and the > 100 000 cfaf income groups respectively. The Statistical Package for the Social Sciences (IBM SPSS) statistical analysis software version 19 was used to calculate the frequencies based on the responses. These frequencies were now used to further calculate the bivariate Pearson correlation coefficient (Motulsky, 1999). The selection of this quantitative method of analysis was based on the fact that it enables us verify if the number of people (male or female) in different income groups is significantly correlated to the respondents perceptions of their access to food and water. Pearson correlation is fitted by the following equation:

$$r = \frac{\sum(x-\mu)(y-\mu)}{D\sqrt{\sum(x-\mu)^2\sum(y-\mu)^2}}$$

Where:

r is the Pearson correlation coefficient, x is the number of respondents in the different income groups and y the number of respondents in the different income groups with perceptions of limited access to food and water. μ is the mean of x and y respectively and D is the division sign. r ranges from: -1.0 to 1.0, where: -1.0 to -0.7 strong negative association, -0.7 to -0.3 weak negative association, -0.3 to +0.3 little or no association, +0.3 to +0.7 weak positive association, +0.7 to +1.0 strong positive association.

To test the goodness of fit of these results, the chi-squared test with significance level at 0.05(5%) and degree of freedom of (6-1=5) was used and the following hypotheses were postulated:

In the case of income levels and vulnerability, the Null hypothesis (H_0) was: There are no differences in population frequencies for all income groups for the expected and observed frequencies. The Alternate hypothesis (H_1) was: There are some differences in frequencies between the observed and expected frequencies for all income groups.

In the case of female respondents and vulnerability, the H_0 was: Female respondents are not less vulnerable than male respondents. The H_1 was: Female respondents are less vulnerable than male respondents.

Finally, in the case of male respondents and vulnerability, the H_0 was: Male respondents are not less vulnerable than female respondents. The H_1 was: Male respondents are less vulnerable than female respondents.

5.5. RESULTS

For the 100 respondents in the *market square* project we had 44 males and 56 females (Table 5.1). Here, it is observed that as the income level increases from <20 000 to >100 000 fcfa, there is a fall in the number of respondents with perceptions of problems with access to food and water. There are slight fluctuations which are not strong enough to puncture the overall inverse relationship. In the case of the 100 respondents in the *outdoor mosque* project, the study shows that there are 61 males and 39 females (Table 5.2).

When the results for male respondents only for both the *market square* and the *outdoor mosque* area are added up, it is observed that we have a total of 105 males (52.5% of the total population of 200) (Table 5.3). From this number, 68 respondents (34% of the entire population of 200 and 64.5% of the 105 males) are faced with problems of limited access to food and water (Figure 5. 3). In the above observations, as the income levels rise, the number of respondents in the different income groups declines and so too does the number of respondents with perceptions of problems of access to food and water (Figure 5.3). In general, it is observed that when the number of respondents in the different income groups is high, there is a higher number of respondents with problems of access to food and water, this is closely linked to the lower income levels, the slight fluctuations are not sufficient to off-set the general trend (Figure 5.4).

Table 5.1. Income levels and gender for the 100 respondents in the *market square* survey

Income Groups(cfaf)	Male	Female	Total
<20,000	11	14	25
20,000-40,000	10	10	20
41,000-60,000	06	10	16
61,000-80,000	07	12	19
81,000-100,000	08	07	15
>100,000	02	03	05
Total	44	56	100

Table 5.2. Income levels and gender for the 100 respondents in the *outdoor mosque* survey

Income Groups(cfaf)	Male	Female	Total
<20,000	14	09	23
20,000-40,000	12	07	19
41,000-60,000	09	08	17
61,000-80,000	11	08	19
81,000-100,000	09	04	13
>100,000	06	03	09
Total	61	39	100

Table 5.3. Income levels of all male respondents and number with limited access to food and water in both the *market square* and the *outdoor mosque* area

Income Groups(cfaf)	Male	Number with limited access to food & water
<20,000	25	20
20,000-40,000	22	22
41,000-60,000	15	12
61,000-80,000	18	06
81,000-100,000	17	07
>100,000	08	01
Total	105	68

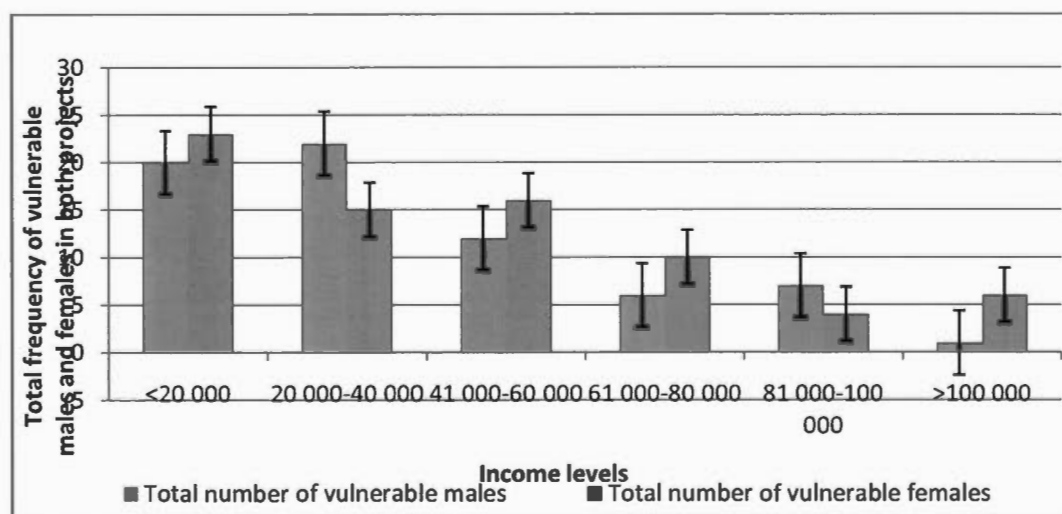


Figure 5.3. Total number of vulnerable male and female respondents in both projects. More females are vulnerable than males as a total of 68 males out 105(64%) are vulnerable to food and water shortages while a total of 74 females out of out of 95 (77%) are vulnerable. Figure is based on data from Tables 5.3 and 5.4.

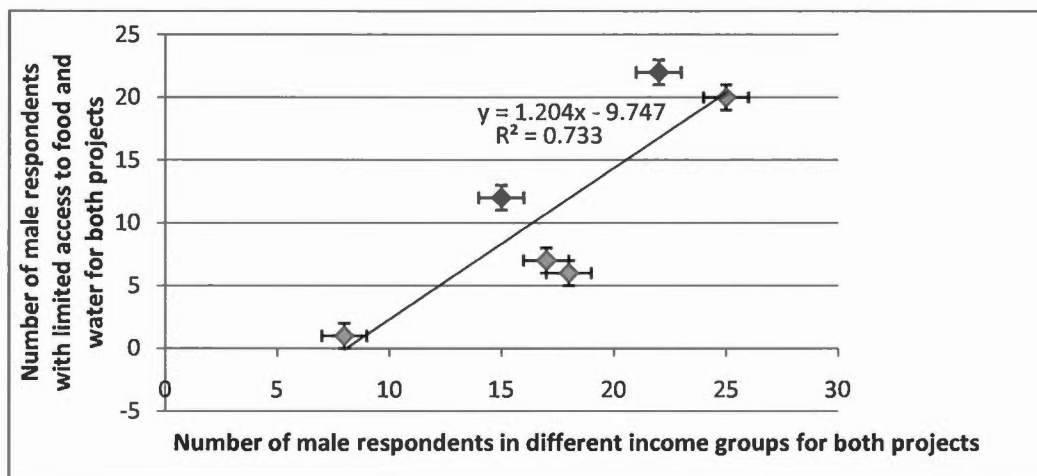


Figure 5. 4. Scatter plot of the total male respondents and the number of respondents with limited access to food and water due to deforestation. A generally rising graph meaning the number of respondents with limited access to food and water increases with increase in the number of male respondents.

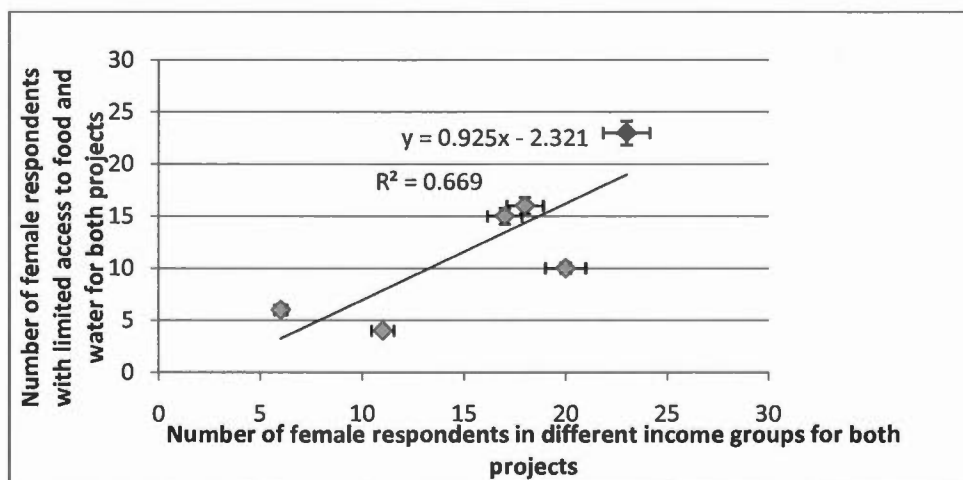


Figure 5. 5. Scatter plot of total female respondents and the number with limited access to food and water due to deforestation. A generally rising graph meaning the number of respondents with limited access to food and water increases with increase in the total number of female respondents.

In the case of the number of females in both projects, it is observed that there are 95 females (47.5% of the total population of 200) and of this number, 74 respondents (37% of entire population of 200 and 77.9% of the 95 females) are vulnerable to food and water shortages (Figure 5.3). The results here reveal that generally females are more susceptible or vulnerable to food and water shortages (Figure 5.3). As the number of female respondents falls with increasing income levels, there is a parallel fall in the number of females with limited access to food and water (Table 5.4). In other words, as the number of respondents in the various income levels increase, there is an increase in the number of respondents with limited access to food and water, at this same time, income levels will be low, the slight fluctuations are not sufficient to off-set the general linear trend (Figure 5.5).

Table 5.4. Income levels of all female respondents and number with limited access to food and water in both the *market square* and the *outdoor mosque* area

Income Groups(cfaf)	Female	Number with limited access to food & water
<20,000	23	23
20,000-40,000	17	15
41,000-60,000	18	16
61,000-80,000	20	10
81,000-100,000	11	04
>100,000	06	06
Total	95	74

Table 5.5. Income levels of combined male and female respondents and number with limited access to food and water in both the *market square* and the *outdoor mosque* area

Income Groups(cfaf)	Total male& females	Number with limited access to food & water
<20,000	48	43
20,000-40,000	39	37
41,000-60,000	33	28
61,000-80,000	38	16
81,000-100,000	28	11
>100,000	14	07
Total	200	142

When the results of male and female respondents for both projects are combined, it is observed that as income levels increase there is a fall in the total number of respondents and the number of respondents with perceptions of limited access to food and water (Table 5.5). In other words, it can be said that when the number of respondents is high, there is a parallel increase in the number of respondents with perceptions of limited access to food and water with equally low incomes (Figure 5. 6 and Figure 5.7).

In the case of the Pearson correlation calculations, three scenarios have been established (Table 5.6). Scenario one shows the results for all males in both projects. A correlation coefficient of 0.86 depicts a generally perfect positive correlation between number in different income groups and number with limited access to food and water. In the case of scenario two, reference is made to all females in both projects. A correlation coefficient of 0.82 also depicts a generally perfect positive correlation between number in different income groups and those with limited access to food and water (Table 5.6). In scenario three, reference is made to results of both males and females combined for both projects. Here, a perfect positive correlation of 0.84 between number in different income groups and number with limited access to

food and water is obtained (Table 5.6). All these results are at a 0.05 significance level.

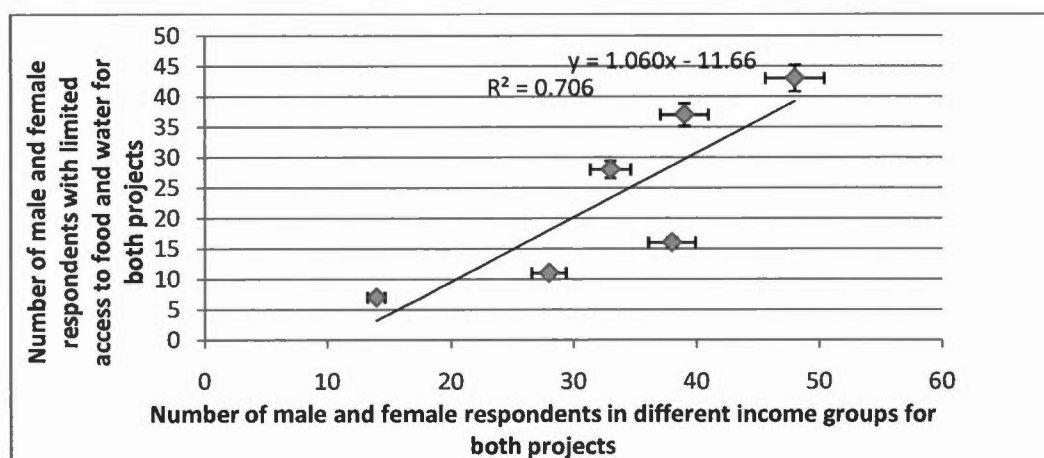


Figure 5.6. Scatter plot of total male and female respondents and the number of respondents with limited access to food and water due to deforestation. A generally rising graph meaning the number of respondents with limited access to food and water increases with increases in the total number of male and female respondents.

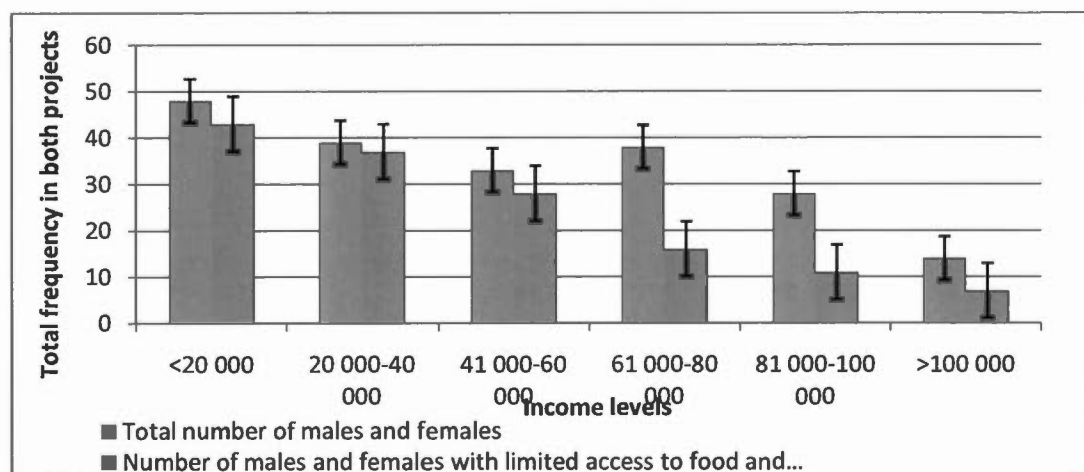


Figure 5.7. Shows the inverse relationship that exists between income levels and the total male and female respondents with limited access to food and water. Figure is based on the totals for both projects and males and females as seen on Table 5.5.

Table 5.6. Pearson Correlation results in three different scenarios between numbers in different income groups and number with limited access to food and water

Outputs	Scenario 1	Scenario 2	Scenario 3
Pearson Correlation (r)	0.856	0.818	0.841
Significance level (sl)	0.05	0.05	0.05
Significant 2-tailed(p)	0.029	0.047	0.036
Number of observations(n)	06	06	06

Scenario 1: Males in both the *market square* and *outdoor mosque* projects

Scenario 2: Females in both the *market square* and *outdoor mosque* projects

Scenario 3: Males and Females in both projects combined

For the chi-squared (χ^2) test on vulnerability according to income levels in both study sites, an χ^2 (for 5 df) of 27.87 is obtained and it is statistically significant at the 5% level, hence the H_0 is rejected while the H_1 is accepted and it is concluded that there are some differences in frequencies between the observed and expected frequencies for all income groups. The H_0 is rejected because the calculated χ^2 (27.87) is greater than the table value of 11.07.

For the chi-squared (χ^2) test on vulnerability of female respondents in both study sites, an χ^2 (for 5 df) of 9.91 is obtained and it is statistically significant at the 5% level, hence the H_0 is accepted and it is concluded that female respondents are not

less vulnerable than male respondents. The H_0 is accepted because the calculated χ^2 (9.91) is less than the table value of 11.07.

For the chi-squared (χ^2) test on vulnerability of male respondents in both study sites, an χ^2 (for 5 df) of 21.61 is obtained and it is statistically significant at the 5% level, hence the H_0 is rejected and it is concluded that male respondents are less vulnerable than female respondents. The H_0 is rejected because the calculated χ^2 (21.61) is greater than the table value of 11.07.

The overall implication of these results is that both the total number of respondents and the number of respondents with limited access to food and water are significantly correlated. When the number of respondents with low income is high, the number of respondents with perceptions of limited access to food and water is equally high (Figures 5.4, 5.5, 5.6). The coefficient of determination (R^2) for all the latter figures is above 60% representing a relatively above average level at which these models are reliable in explaining the observed trends. In other words, when incomes are low, there are more respondents and also more respondents who have problems of food and water and when income levels are high, there are fewer respondents and a lower number of respondents who have problems of limited food and water reduces. It can be said that the poor with low incomes are more vulnerable to the effects of deforestation while those with higher income who are considered richer in relative terms and are less vulnerable. The number of poor respondents is higher than the number of rich ones and the community could be described as a generally poor community with high levels of vulnerability as seen from this sample of 200. In the same way, women are reported to be more vulnerable than men (Figure 5.3).

The common reasons given by the respondents why the poor are more vulnerable are linked to the fact that poor people generally do not have the means to be able to purchase enough food and water in times of famine or water scarcity (droughts). The

rich can easily adapt by buying, a capacity which the poor do not have. The low income groups are not only limited in their ability to buy food and water but are mostly farmers who cannot afford fertilizers, improved seeds and machinery, thus, years of low yields are followed by years of reinforced low yields. Women, on the other hand, are said to be vulnerable because from a cultural stand point, the area is an African Muslim community in which women are traditionally responsible for fetching water and food for household consumption. When there is scarcity of food and water, the women suffer more because they have to cover longer distances to fetch water and work longer hours on their farms. The males are traditionally responsible for rearing cattle which leaves women with no options than to walk and work longer hours to fetch water and cultivate crops to get very low yields.

5.6. DISCUSSION

The concept of vulnerability along gender and poverty lines has been discussed in social theory. As concerns gender, the power control and structuration theories have been very helpful in developing the ideas. These theories argue that social constraints vary with gender. This is reproduced across generations as is the case in most male dominant societies. In such power structures, gendered stratification is such that women are assigned larger roles than men in both the control of children and handling of domestic issues including the provision of food and water for the family (Hagan, 2008). In the area of poverty and vulnerability, perhaps the theory of vulnerability as a symptom of poverty is of vital consideration. This theory argues that the inability for people to be able to absorb environmental shocks is often linked to a lack of means. In this way, vulnerability is said to be tightly linked to the inability of a population to absorb shocks such as natural hazards, famine, droughts and diseases (Prowse, 2003). Many other studies have further analysed the issues of population vulnerability to man-made environmental hazards such as famine and water scarcity. It has been argued from a socio-economic or income level stand point

that the ability to absorb losses and improve resilience to food and water scarcity varies with wealth or income levels of those concerned. Wealth enables the communities affected to be able to absorb and recover from loss rapidly due to social safety nets, insurance and entitlement programs. All these wealth related factors place communities in a better position to be less vulnerable (Cutter *et al.*, 2003; Cutter *et al.*, 2000; Burton *et al.*, 1993; Blaikie *et al.*, 1994; Peacock *et al.*, 1997; Hewitt, 1997; Platt, 1999).

In addition, the World Food Program (WFP) supports this view point when it argues that the poor masses in Yemen have lower accessibility to food and water. There is a close relationship between food insecurity and poverty; some households are said to be food insecure because of poverty, insecure and vulnerable people belong to the poorest households and malnutrition and lack of access to good drinking water are all caused by poverty. However, the report also holds that, some rich households are also found with problems of food insecurity while some poor households do not (WFP, 2009).

From a developed/developing world perspective, the capacity to survive and recover from the repercussions of man-made hazards such as famine and food shortages is argued to be controlled by the socio-economic conditions of social groups or individuals in the developing and developed countries. In other words, vulnerability is differentiated by social groups in most natural and man-made hazards. About 70 % of people in developing countries are more vulnerable than in developed countries (Martine and Guzman, 1999).

From a gender stand point, it has been argued that women appear to be more vulnerable. This is seen as women can have more difficulties recovering from man-made hazards such as famine and water scarcity than men. This high level of vulnerability has been associated to the fact that women have family care responsibilities which ties them more to issues such as providing food and water for

their families. This has also been attributed to sector specific employment and wage differentials in which women are generally paid lower wages than men (Blaikie et al., 1994; Enarson and Morrow, 1998; Enarson and Scanlon, 1999; Morrow and Phillips, 1999; Hewitt, 1997).

In Vietnam, women have also been found vulnerable to declines in water and food supplies. Between 2001 and 2007, 500 000 hectares of land was lost to industrial parks in Vietnam and the resultant food declines had negative impacts on women who were described as the hardest hit. The reason advanced for this high level of female vulnerability was linked to the fact that women are less able to take advantage of new employment opportunities (mobility of labour) (Jones and Anh, 2010). The effects of climate change and deforestation are similar; they may include famine, water scarcity and rising temperatures inter alia. According to the United Nations (UN, 2007), in many of these situations, women in developing countries have been found more vulnerable than men. The primary reason for this gender oriented vulnerability is linked to the fact that women constitute a majority of the world's poor masses and are more dependent on natural resources that are threatened by climate change and deforestation.

5.7. CONCLUSION

This study has quantitatively evaluated the relative vulnerability of the rich and the poor on the one hand and males and females on the other to the two principal effects of deforestation (Food and water shortage). Overall, women and lower income groups are more vulnerable while the number of vulnerable is significantly correlated to the total number of respondents per income group. Chi-squared tests also show that the results are valid and significant with respect to the data and the hypotheses. The application of population perceptions and Pearson correlation techniques are vital in determining population vulnerability to the effects of deforestation. This approach remains vital because it can often be said that this or that segment of society is vulnerable to food and water scarcity but such conclusions will make little or no

meaning if we cannot test the validity of such statements empirically. Again, the use of population perceptions gives us an inside into the sufferer's perception of the problem which in most cases reflects what really obtains on the ground. In Africa where data on such issues are difficult to come by, such sample studies create a good framework for policy makers.

It is necessary to consider these results in relative terms and not in absolute terms. The results are based on a sample of 200 respondents and human behavior remains uncertain as reflected in perceptions. Poverty itself is a complex issue that may not be weighted by income levels only. Whatever the weaknesses, the sample size and the uncertainties in human decision making do not hamper these results since models remain a way of thinking. Ford, (1999) said, "The important question is not 'Is the model valid?' but 'Is the model useful?'" We urge more improvements in the sample size, prognostic studies into the future, and evaluations of the behavior of the age variable on a broad scale and comparison of the relative vulnerability accounted for by deforestation and climate change.

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CHAPTER VI

ENABLING CONDITIONS FOR SUCCESSFUL GREENING OF PUBLIC SPACES: THE CASE OF TOUROUA, CAMEROON BASED ON PERCEPTIONS

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6.1. RÉSUMÉ

Cette étude cherche à vérifier la perception des hommes et des femmes aux incidences et aux causes de succès de la plantation d'arbres dans deux espaces publics à Touroua, Cameroun. Cette approche est motivée par les hauts niveaux d'échec de la plantation d'arbres enregistrée au Cameroun. Cette étude essaie également d'analyser ce que les répondants perçoivent comme succès et échec dans la plantation d'arbres. Les données ont été obtenues par l'administration aléatoire de 200 questionnaires dans le site d'étude. Les données ont été analysées utilisant SPSS (Statistical package for the social sciences, version 19) pour calculer les fréquences, les pourcentages et les chi carrés. Les résultats prouvent que la cause principale du succès dans la plantation d'arbres est la participation active de la population alors que l'absence d'une telle participation est la cause principale des échecs. Ces résultats sont statistiquement significatifs tels que démontrés par les tests de chi-carré. Pour la plupart des répondants, la signification d'une campagne réussie de plantation d'arbres est quand les arbres deviennent mature ou entièrement établis. Quand les arbres ne deviennent pas matures ou entièrement établis, on considère la plantation d'arbres comme un échec.

6.2. ABSTRACT

This study seeks to verify the perceptions of respondents on the meaning and causes of success or failure in tree planting in public spaces and whether the two specific projects were successful or failures. This was verified because the meaning and causes of success or failure in tree planting and whether a project is a success may have different meanings to different people in different parts of the world. This evaluation is motivated by the rising rates of tree planting failures recorded in Cameroon. Data were obtained through a focus group discussion (FGD), interviews with key informants, researcher's observations and a survey. Statistical testing revealed that a major factor in success in tree planting is the active involvement of all stakeholders in the design, elaboration and implementation of the projects. Another factor is the diversification of livelihoods; when livelihoods are diversified the indigenes tend to have alternative income sources and reduced dependence on trees. To most respondents, the main criterion for judging success of a project is that trees grow to maturity/harvest age or become fully established.

Keywords: perceptions, public spaces, reforestation, stakeholder participation, harvest age

6.3. INTRODUCTION

Human population growth has been found to be the principal cause of deforestation globally, and including Cameroon (Vitousek *et al.*, 1997; Zhao *et al.*, 2006; Epule *et al.*, 2011; Epule *et al.*, 2013). Wide scale deforestation has been responsible for food insecurity, water scarcity and increase in atmospheric carbon dioxide in sub-Saharan Africa (SSA), and Cameroon in particular (Armenteras *et al.*, 2010; Epule *et al.*, 2012). To reverse this situation, many communities, governments, donor organizations and non-governmental organizations (NGOs) in many parts of the world, including in Cameroon, have resorted to regreening the landscape through tree planting projects.

Between 2000 and 2010, the net annual loss of forest in Africa stemming from deforestation averaged 3.4 M ha (FAO, 2010a, b). This rate is lower than what was experienced in Latin America, which lost 4.0 M ha per year during the same period. However, SSA still lags behind in attempts at reducing vegetation loss when compared to Europe and Asia which between 2000 and 2010 had net regreening gains of 0.7 M ha and 2.2 M ha per year, respectively (FAO, 2010a, b). Most academic studies on reforestation in Africa and Latin America are either simplistic or generalized such that they are speculative and fail to examine the particular causes of the problem (Agarwal *et al.*, 2005). The study of reforestation is made even more complicated in that appropriate solutions vary between regions due to intricate environmental, cultural, political, economic and socio-cultural differences.

Little evaluation of the success of tree planting projects in public spaces has been undertaken in Cameroon. *Public spaces* are viewed here as areas within the community used by the indigenous people on a daily basis and exclude all land that is managed for timber production. These include the *market square* and the *outdoor mosque*. This paper is the first that attempts to study people's perceptions of the

causes of success and failure of tree planting projects in public spaces in Touroua, Cameroon. The study was conducted because: (1) Cameroon experiences a net loss of about 220 Kha of forests annually (about 1% of its remaining 28 Mha of forests) (FAO, 2010a and b); (2) the study area is in the drier and fragile ante-room (core) of desertification and climate change in Cameroon; and, (3) several studies have evaluated issues relating to tree planting in the south of the country or other parts of the tropics where there is a humid tropical forest, but none has dwelled on the issue of success factors in any reforestation projects in Cameroon.

With respect to related studies, Duguma and Tonye, (1994) analyzed multipurpose tree and shrub species for agroforestry in the south of Cameroon, and Duguma *et al.*, (1994) examined the growth of multipurpose trees on acid soils. Schreckenber *et al.*, (2002) analyzed the importance of *Dacryodes edulis* in southern Cameroon, Simmons *et al.*, (2002) compared Panama and Brazil with respect to tree planting by small producers, Degrande *et al.*, (2006) examined fruit trees growing strategies, and Harrison *et al.*, (2008) examined the production of forestry seedlings in Asia. The work of Le *et al.*, (2012) probably comes closest to the objective of this current study in that it assesses the causes of reforestation success in tropical developing countries in terms of technical/biophysical, socio-economic, institutional, policy and management drivers of reforestation outcomes. However, there is still a great need for studies to evaluate past and continuing reforestation projects in both the drier-fragile north and humid tropics, including the south of Cameroon, most existing studies having a focus on Asia and Latin America.

A study on forest management in Nepal has illustrated the usefulness of population perception studies in resource management. It has been argued that the mechanisms for community based forest management need to be based on the *real-life* experiences of those living close to the forests and not on top-down decision-making (Bartlett and Malla, 1992; Pokharel *et al.*, 2007). In this context, it has been concluded that

community forest groups are viable structures for sustaining forests in Nepal (Pokharel *et al.*, 2007). In general, people's perceptions are increasingly being considered in forest management. There are examples of such evaluations in Africa south of the Sahara, New England, Tasmania, Ethiopia and Nepal (Mackay, 1978; Napier and Napier, 1991; Hartup, 1994; Colchester, 1996; Sall, 1996; Hill, 1999; Close and Davidson, 2002; Smith, 2003; Urgessa, 2003; Pokharel *et al.*, 2007; Sendzimir *et al.*, 2011; Degrande *et al.*, 2012). In Ethiopia a survey of farmers revealed that a high proportion acknowledged that their forest cover was declining and they would be interested in tree planting if private ownership of trees and forests could be authorized (Urgessa, 2003; Bogale and Urgessa, 2012). In general, people's perceptions are increasingly being considered in forest management, the approach adopted here. The entire approach of considering the opinions of the 'grassroots' in decision-making is gaining ground.

In this study, the word *maturity* is used to denote trees that have attained harvest or production age for timber, fruits or other products. Neem trees produce fruits two to three years after planting, although they take about 10 years to reach full production. Food yields are used to denote the effects of the trees on farm outputs. The *diversification* of livelihood activities in this study means involving the people in other livelihood activities such as raising livestock in ranches, 'small businesses' or trade, thus reducing their dependence on the trees for either fuel or income. *Personalization* of task involves assigning responsibility for the care and survival of a specific number of trees (for example watering, removing weeds and protecting trees from being eaten by animals) to specific individuals to enhance care and survival. This is what Taylor, (1993) described as, 'where local people are genuinely in control of management of forest resources.'

This evaluation is motivated by the fact that perceptions are an important component of environmental impact assessment and understanding the perceptions of the people

provides a framework for better results (e.g. Dolisca *et al.*, 2007). This study examines one successful tree planting project and one failed project in Touroua, North Region of Cameroon. People's perceptions are analyzed to verify their understanding of what success and failure in tree planting is about, their judgment of whether the projects were successful and the reasons for these judgments. This evaluation is important because if the causes of success in tree planting in public spaces are understood, it is easier to design other projects along the same line while considering the environmental, socio-cultural, economic and political differences of the people involved. The key questions this study addresses are: (1) was reforestation a success or failure in the study area? (2) how would a successful or failed reforestation project be judged? (3) what are the perceptions of the population concerning the reasons for success or failure of the reforestation projects?

6.4. THE STUDY AREA

Touroua is in the south west of the North region of Cameroon, 52.4 km from Garoua, the Capital of the North Region of Cameroon. It is situated at latitude 9.0833° N and longitude 12.9667° E (Figure 6.1). It has a Sudano-Sahelian climate in which annual rainfall is about 900 mm and average annual temperature ranges of 25°C with seasonal peaks of about 39°C during the dry season. It has Guinea Savanna vegetation mixed with trees of various species among which is the Neem tree (*Azadirachta indica*). The main soil types in this region are chromic vertisols, vertisols, planosols, and the Albic and Stagnic Luvisols (Dounias *et al.*, 2002; Sevink *et al.*, 2004). Generally, these soils are thin and very dry and are often mostly suitable for the cultivation of grains and are able to sustain trees if they are planted at the right time of the year, if the trees are drought resistant as is the Neem tree and if the trees are managed carefully (Sevink *et al.*, 2004).

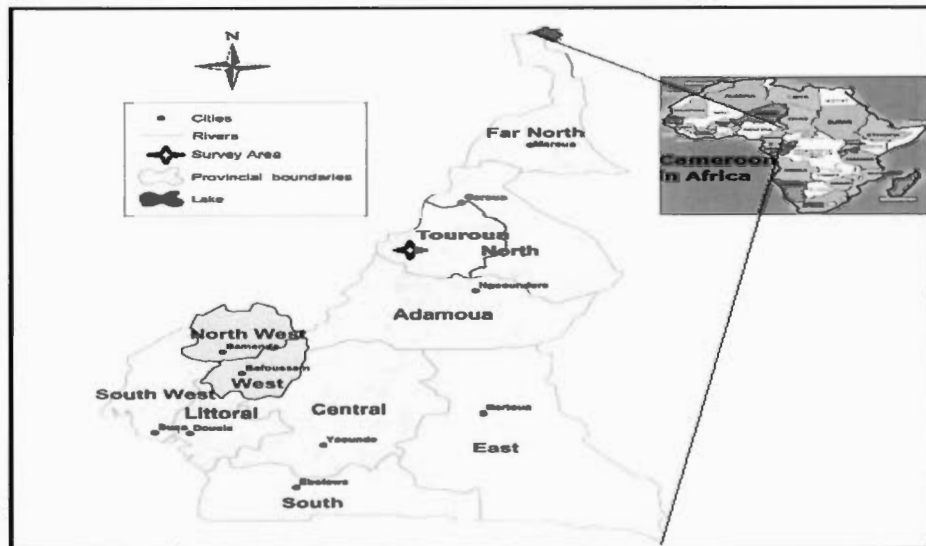


Figure 6.1. Location of study area in Africa and Cameroon.

Source: Modified from Fontem *et al.*, (2005).

Since both projects were carried out in the same community, this study assumes uniform average annual rainfall, average annual temperatures and similar soils for both areas. Although the trees for both projects were planted at different times of the year, water supply was equally variable and remained a crucial variable in tree survival. Also, the high rates of deforestation in the North Region of Cameroon are essentially due to the high rates of immigration from the Far north. The North region has a rate of immigration of 5.1%, much higher than the national level of 3.2%; this further demonstrates the role of population changes in explaining tree loss in Cameroon. Njiti and Sharpe, (1994) and Epule *et al.*, (2011) evaluated the drivers of forest loss in Cameroon and found population growth as a dominant factor.

The *outdoor mosque* is a religious site used for Friday prayers while the *market square* is a commercial site where the daily trade market takes place. Trees are of great value in these areas because they serve as shade to the users and have ecological benefits such as regulating the hydro-carbon cycles, providing environmental

aesthetics and sustaining food supply. Evaluating the reasons why the trees in the two projects succeeded or failed serves as a blueprint for the evaluation of other small-scale tree planting projects in Cameroon.

6.5. INCEPTION AND MAINTENANCE OF PROJECTS

The first of the projects examined (*market square* tree planting project) took place in 2000 and by the end of 2002 the trees were well established and in production. Of the 533 Neem trees that were planted in the rainy season of 2000 (May-June), 460 were still alive in 2002. When this study was conducted in 2011, all these trees were still alive (86.30% success rate). The total size of the planted area was 1 ha. Planting under the second project (the *outdoor mosque* tree planting) took place in the dry season of 2001 (October-November). A total of 533 Neem trees were planted in an area of 1 ha. By the end of 2002, only 221 trees had survived and at the time of data collection in 2011 only 68 of these trees had survived (12.75% success rate).

These two projects were initiated by a Peace Corp Volunteer. Once the projects were approved and the sites for the planting allocated, the Lamido or traditional ruler, the Divisional Officer, the Mayor, the peace Corp Volunteer and the indigenes proceeded to create a nursery for the production of seedlings. The seeds for the *market square* and *outdoor mosque* projects were planted in 1999 and grown in a single nursery in polybags filled with compost, soil and sand.

The maintenance of the nursery involved watering, removal of invasive weeds and protection (from animals, pests and the sun). After two to three months, the seedlings were ready for outplanting. In the case of the *market square* project, the indigenes planted the seedlings with a mixture of cow dung and compost. Treeguards were used to protect the trees from invaders such as sheep and cattle. The protections were usually made of thorny branches which were repellant to invaders. Groups of indigenes were assigned the responsibility of watering the trees and removing weeds.

In the case of the *outdoor mosque*, there was little training of the planters and the seedlings were outplanted without compost, treeguards or adequate watering.

6.6. RESEARCH METHOD

One focus group discussion (FGD) was held with tree growers, cattle herders, farmers, traders and teachers of the local primary school. The FGD was conducted by the researchers and three research assistants. All the research questions were read out and explained to the participants. In cases where the participants did not understand because of language barriers, a research assistant that spoke Fulfulde provided the explanation. The participants were also asked to give reasons for their opinions on their choices of responses during the FGD. One key informant was also interviewed to provide an overview of the projects; a field assessment and desk studies were also conducted.

After the FGD, a survey of tree growers, farmers, cattle herders, traders and teachers was conducted, in which a simple random sample of 200 respondents was taken from a total population of nearly 900 people. Equal sub-sample sizes (100) were taken for the *market square* and *outdoor mosque* sites. The survey was designed to obtain the perceptions of the people about the level of success of the projects from segments of the population that are representative of the entire population. The respondents were male and female household heads. The data were prepared for analyses on two Excel spreadsheets representing the two projects, and then uploaded into SPSS version 19 for the calculation of descriptive statistics.

The reliability of the results on the *market square* project for reasons for success and on the *outdoor mosque* project for reasons for failure were tested with the use of the chi-squared (χ^2) statistical test of goodness of fit of the sample data to the uniform population distribution of reasons for success or failure. A 5% significance level was

adopted. The hypotheses used are as follows: Null hypothesis (H_0) is that the population proportion is equal for each reason for success or failure. The alternate hypothesis (H_1) is that there is some difference between population proportions between reasons for success and failure, i.e. some reasons for success or failure are more important than others. As a rule, if the calculated chi-squared statistic is higher than the critical table value, the H_0 is rejected in favour of H_1 . Note that the order of importance of the reasons for success or failure is descriptively judged by the ranking of frequencies with no statistical basis for ranking.

6.7. RESULTS

The majority of respondents can be described as low income respondents (see Table 1). This is linked to the fact that the average annual income in Cameroon is 619,618 fcfa (1200 USD)¹ (United Nations (UN) 2012). Most respondents had monthly incomes below the national monthly average (as reported by Epule *et al.*, 2012).

According to a key informant, the exotic Neem² trees were selected for these projects because: they are highly attractive; they have rapid growth and commence production after two years; they reach a height of about 15-20 m at the age of 10 years; they are evergreen which makes them suitable for soil protection all year round; they have spreading branches that protect the soil from the rays of the sun; they protect the soil from erosion and restore the land phase of the hydrological cycle; they have hard bark that reduces the risk of damage from herbivores, the sun and the wind; they are drought resistant and well suited for dry environments; they form a dense round canopy making them good as shade trees; they have fruits which can also be used for food, to produce oil and soap, and other purposes.

¹ 1 USD was equivalent to 510.098 fcfa in July 2011.

² Other tree types common in this community but not used in these projects are, Baobab (*Adansonia digitata*), Yellow Cassia (*Cassia siamea*), Eucalyptus (*Eucalyptus camaldulensis*) and Red Mahogany (*Khaya senegalensis*).

Table 6.1. Total annual household income levels for both projects

Income groups (1000 cfaf)	Total males and females	Males	Females
<20,000	48 (24%)	25	23
20,000-40,000	39 (19.5%)	22	17
41,000-60,000	33 (16.5%)	15	18
61,000-80,000	38 (19%)	18	20
81,000-100,000	28 (14%)	17	11
>100,000	14 (7%)	08	06
Total	200 (100%)	105	95

Source: Adapted with permission from Epule *et al.*, (2012).

In the *market square* tree planting project there were 44 male respondents. Eleven (25%) had the perception that the number of trees that grew to harvest age or maturity was the most important description used to judge the meaning of success in tree planting (Table 6.2). The three other factors in order of importance were trees being able to provide shade 9 (20%), increased food yields 9 (20%) and more carbon sequestration 8 (18%) (Figure 6.2a). Out of the 56 female respondents in the *market square* tree planting project, 17 (30%) had the perception that the number of trees that attained harvest age or grew to maturity was the most important indicator of success in tree planting. The three other factors in order of importance were improved food yields 12 (21%), trees being able to provide shade 11 (19%) and increased carbon sequestration 6 (10%) (Figure 6.2b). In terms of both male and female respondents in the *market square* tree planting project, 28 (28%) had the perception that the number of trees that attained harvest age or grew to maturity was the most important indicator used to judge the meaning of success in tree planting. The three other factors in order of importance were increased food yields 21 (21%), trees being able to provide shade 20 (20%), improved carbon sequestration 13 (13%), and the amount of fuel wood obtained from trees 13 (13%) (Figure 6.2c).

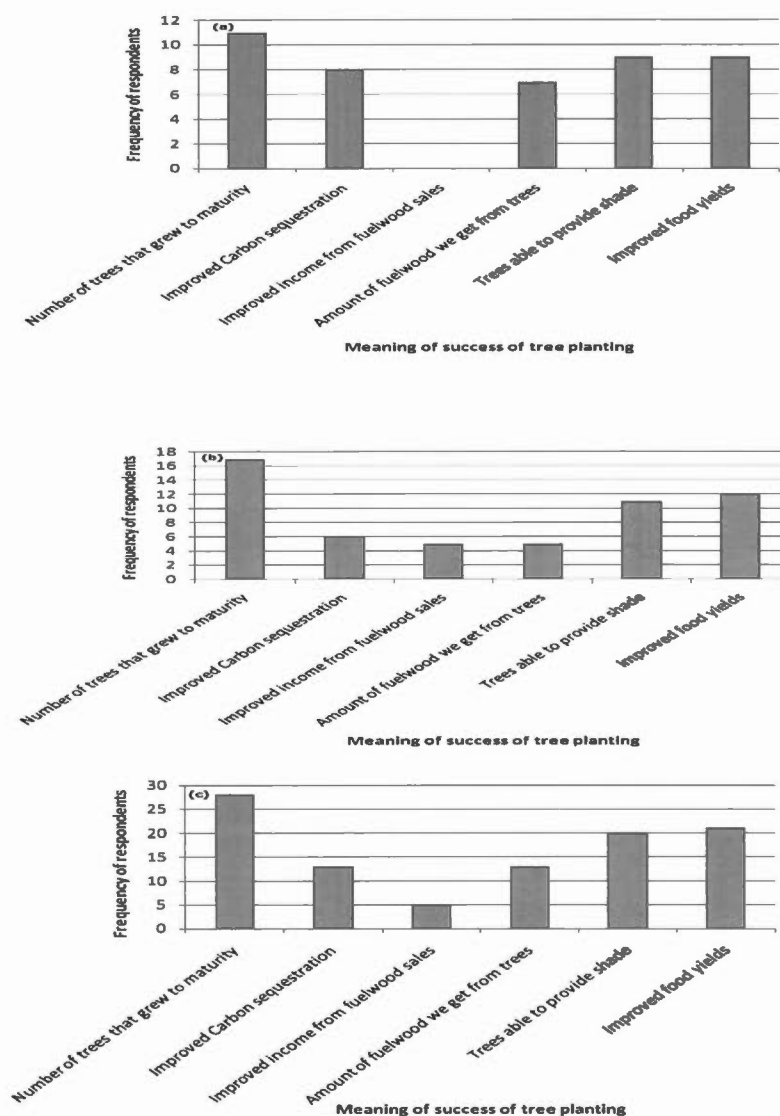


Figure 6.2. Perceptions of (a) male, (b) female and (c) male and female respondents on the judgment of the meaning of success in tree planting in the market square tree planting project.

Of the 44 male respondents in the *market square* project, 30 (68%) said that the project was a success. Out of the 56 female respondents in the project, 43 (77%) said the project was a success. Of all the 100 respondents in the *market square* tree

planting project 73 (73%) considered the project to be a success. From these results, it can be said that the *market square* tree planting project was a success. The most important reasons or causes of success to male respondents in order of importance were diversification of livelihood activities, training of planters and personalization of task (cumulatively third) (Figure 6.3a, Table 6.2). To the female respondents, the four most important causes of success in tree planting in order of importance were population or stakeholder participation, diversification of livelihood activities, personalization of task and training of planters (Figure 6.3b, Table 6.2). When all these responses are added up, it is observed that for both male and female respondents, the four most important causes of success in order of importance were population or stakeholder participation, diversification of livelihood activities, personalization of task and training of planters (Figure 6.3c, Table 6.2).

Table 6.2. Assessment of respondents' perceptions of reasons of success of tree planting in the *market square*

Reason for success	Males	Rank	Females	Rank	Males&females	Rank
Population participation	7	2	12	1	19	1
Use of fertilizers (cow dung)	2	6	0	9.5	2	7.5
Training of planters	5	3.5	5	4	10	4
Personalization of task	5	3.5	7	3	12	3
Existing policy framework	0	7.5	0	9.5	0	10.5
Diversification of livelihood	8	1	8	2	16	2
Declining food yields	0	7.5	2	7.5	2	7.5
No-cultural ties to some species of trees	0	7.5	0	9.5	0	10.5
Sufficient water	3	5	4	5	7	5
No religious ties to land used for planting	0	7.5	2	7.5	2	7.5
No leadership problems	0	7.5	3	6	3	6
Total success cases	30		43		73	
Total respondents	44		56		100	

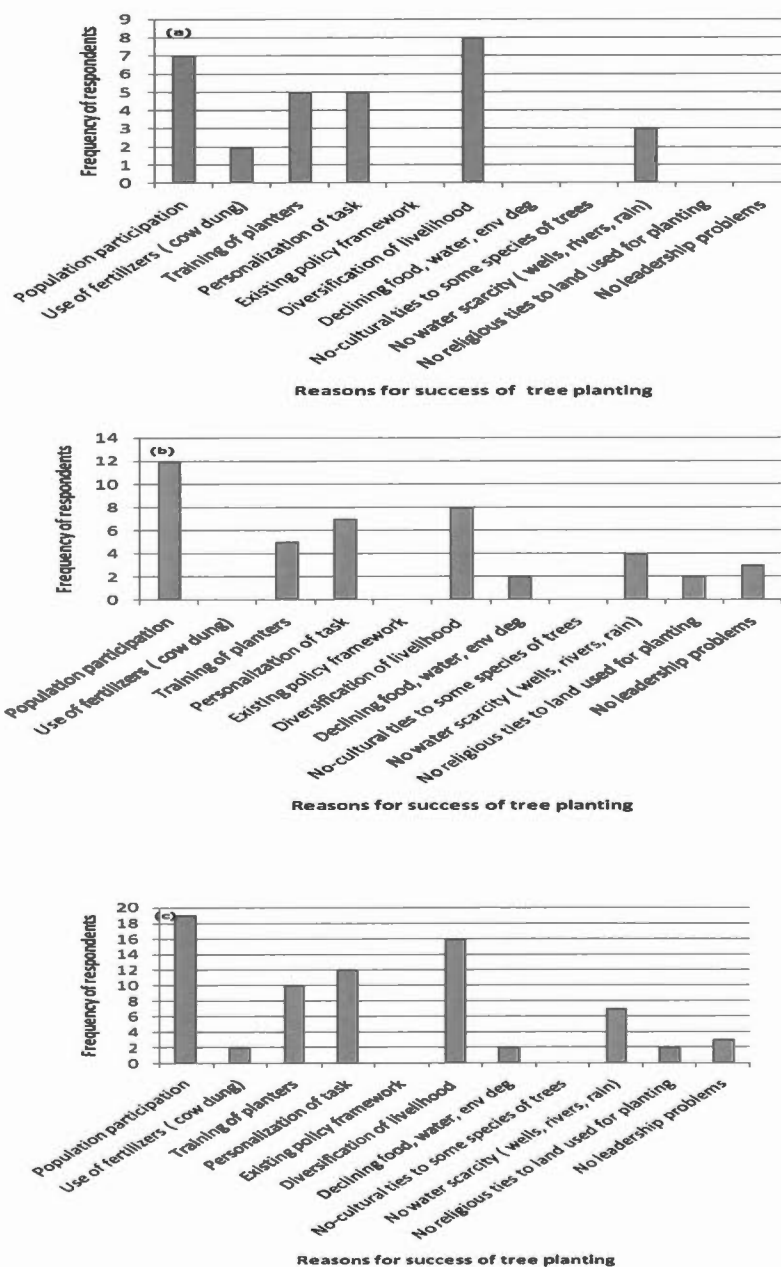
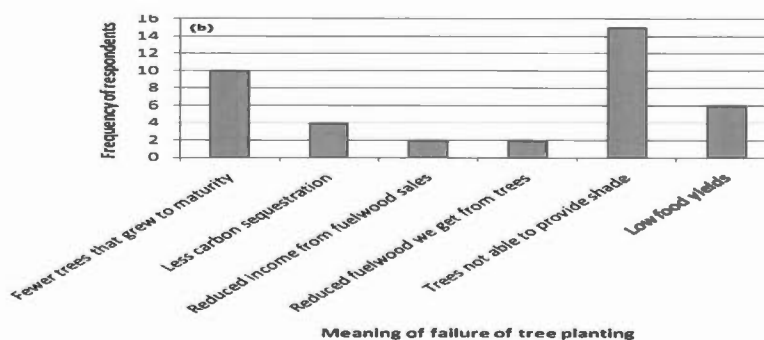
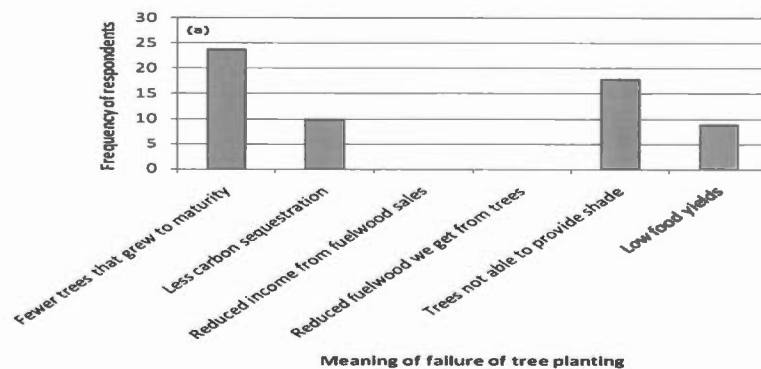


Figure 6.3. Perceptions of (a) male, (b) female and (c) male and female respondents on the causes of success of the market square tree planting project.

In the *outdoor mosque* project, the respondents' perceptions used to judge the meaning of tree planting failure were as follows: Out of the 61 male respondents, 24

(39%) had the perception that a small number of trees growing to harvest age or maturity was the most important indicator of failure in tree planting. The three other factors in order of importance were trees not being able to provide shade 18 (29%), reduced carbon sequestration 10 (16%) and low food yields 9 (14%) (Figure 6.4a). Out of the 39 female respondents, 15 (38%) had the perception that trees not being able to provide shade was the most important indicator used to judge failure in tree planting (Figure 6.4b). The three other factors in order of importance were few trees growing to harvest age or maturity 10 (26%), low food yields 6 (15%) and reduced carbon sequestration 4 (10%). Out of the 100 male and female respondents in this project, 34 (34%) had the perception that a relatively small number of trees growing to harvest age or maturity was the most important indicator of failure in tree planting. The three other factors in order of importance were trees not being able to provide shade 33 (33%), low food yields 15 (15%) and reduced carbon sequestration 14 (14%) (Figure 6.4c).



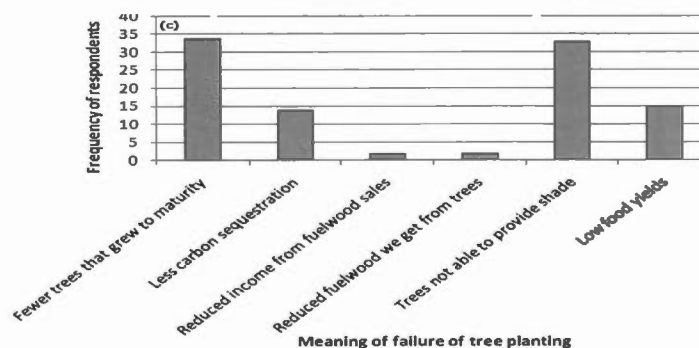


Figure 6.4. Perceptions of (a) male, (b) female and (c) male and female respondents on the judgment of the meaning of failure in tree planting in the outdoor mosque tree planting project.

Concerning whether the *outdoor mosque* project was a success, of the 61 male respondents in this project, 46 (75%) said that it a failure. Out of the 39 female respondents, 25 (64%) said it was a failure. In total, 71% of respondents thought the project was a failure. From these results, it can be said that the *outdoor mosque* tree planting project was considered a failure.

The most important reasons that were responsible for failure in tree planting in the *outdoor mosque* according to male respondents were: limited population or stakeholder participation, no diversification of livelihood activities, water scarcity and leadership problems (Figure 6.5a, Table 6.3). For the female respondents, the four most important causes of failure in order of importance were limited population or stakeholder participation, leadership problems, no diversification of livelihood activities and lack of training of planters for planting (Figure 6.5b, Table 6.3). When all these responses are added up, it is observed that for both male and female respondents, the four most important causes of failure in order of importance were limited population or stakeholder participation, no diversification of livelihood activities, scarcity of water and leadership problems (Figure 6.5c, Table 6.3).

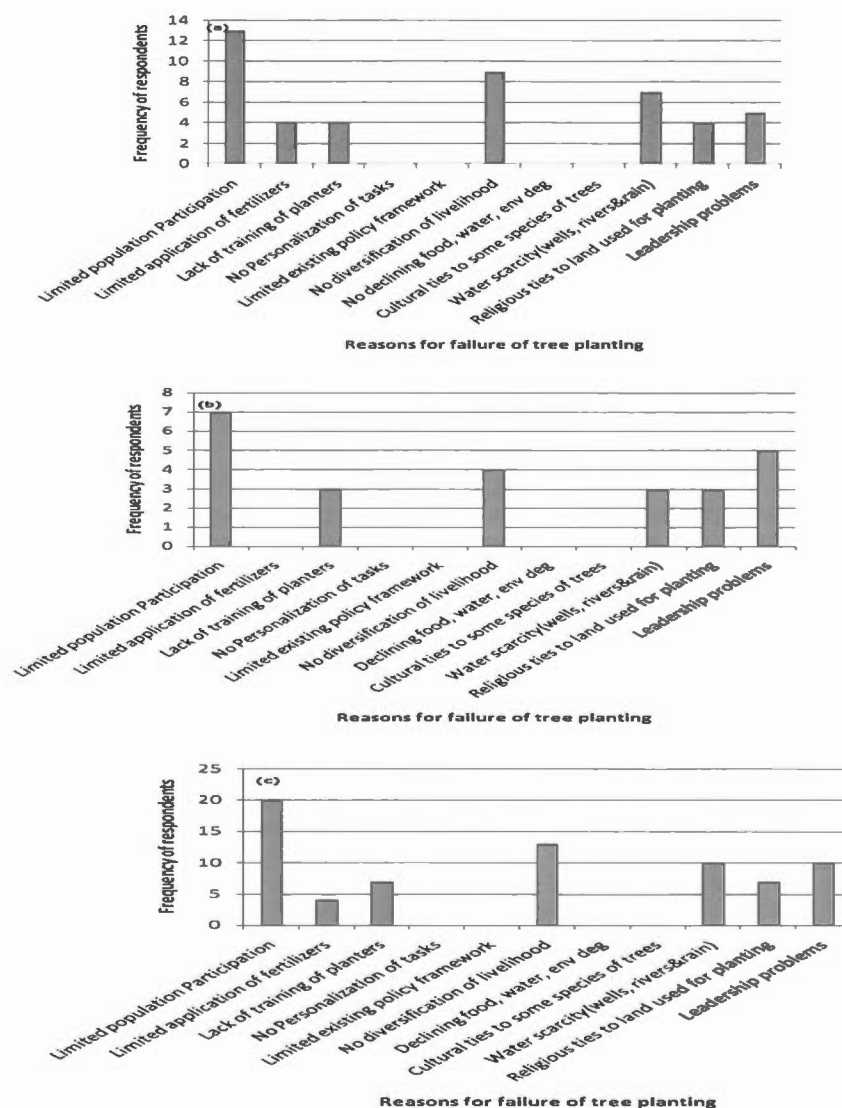


Figure 6.5. Perceptions of (a) male, (b) female and (c) male and female respondents on the causes of failure in tree planting in the outdoor mosque tree planting project.

Table 6.3. Assessment of respondents' perceptions of reasons of failure of tree planting in the *outdoor mosque*

Reasons for failure	Male	Rank	Female	Rank	Males&females	Rank
Limited population participation	13	1	7	1	20	1
Limited use of fertilizers	4	5.5	0	7.5	4	7
Lack of training	4	5.5	3	4.5	7	5.5
No personalization of task	0	8.5	0	7.5	0	8.5
Limited existing policy framework	0	8.5	0	7.5	0	8.5
No diversification of livelihood	9	2	4	3	13	2
No declining food yields	0	8.5	0	7.5	0	8.5
Cultural ties to some species of trees	0	8.5	0	7.5	0	8.5
Water scarcity	7	3	3	4.5	10	3.5
Religious ties to land used for planting	4	5.5	3	4.5	7	5.5
Leadership problems	5	4	5	2	10	3.5
Total failure cases	46		25		71	
Total respondents	61		39		100	

Table 6.4. Results of the Chi-squared test of goodness of fit between the observed and expected reasons for success and failure in tree planting

Observations	<i>market square</i>	<i>outdoor mosque</i>
Calculated χ^2	52.46	54.97
Table value	3.94	3.94

For the test on the reasons for success in tree planting in the *market square* project, the calculated χ^2 (for 10 df) of 52.46 is statistically significant at the 5% level, hence the null hypothesis is rejected and it is concluded that some of the reasons for success are more important than others. Similarly, for the *outdoor mosque* project and based on the frequencies of all male and female respondents, χ^2 (10 df) is 54.97, significant at the 5% level. Again, the null hypothesis is rejected, and it is concluded that some

of the reasons for failure are more important than others. Overall, these results indicate that some of the reasons investigated for project success or failure are more important than others.

6.8. DISCUSSION

Generally, these results are consistent with several independent studies such as (Mackay, 1978; Spears, 1983; White, 1983; Wylie and Johnston, 1984; Close and Davidson, 2002 e.t.c). The main reason advanced for the success of the *market square* project was population or stakeholder participation. Tree planting projects are said to be successful when locals are involved and when they know that to achieve success is also to their benefit (Le *et al.*, 2012). Participation includes a strong government commitment to tree planting which also entails the allocation of financial and human resources, a tradition of communal help which involves the indigenes as well as local farmers who plant trees on their own homesteads and the participation of international organizations. Participation is said to be effective when the indigenous people are included in the choice of trees to be planted as was the case in Nepal, China, most of Asia and New England (Mackay, 1978; Spears, 1983; White, 1983; Zhang *et al.*, 2002; Moon and Park, 2004). According to FGD and a key informant interview, this project was particularly successful due to the involvement of key stakeholders including, the Mayor, Secretary General, Divisional Officer of Garoua, Peace Corps Volunteer, the Lamido and the inhabitants of Touroua in the choice of the type of trees to be used as seedling, the choice of the site for planting and their physical involvement in planting that created ownership and a desire for success. All facets of the society were considered not just as participants but also in the design, conception and realization of the entire project. This increases ownership and brings the project closer to the people.

The diversification of livelihood activities is the second reason advanced for the success of the *market square* project. One way of stopping the indigenes from cutting

trees is through the diversification of livelihood activities through the provision of credits, cash or other incentives which can make farmers to take up tree crop planting as a means of subsistence. This is why they do not have to resort to logging to meet their basic financial or fuel wood needs (Spears, 1983; Higgins *et al.*, 1989; Chokkalingam *et al.*, 2006; de Jong *et al.*, 2006). In the case of the *market square* tree planting project, the people of the area were taken off tree cutting for livelihood survival through the introduction of other activities that substituted the income lost from fuel wood fetching and the loss of food for their cattle. Some of these aspects of diversification included the introduction of domestic animals such as rabbits, cane cutters and the encouragement of rearing of cattle and sheep in ranches. Diversification of livelihoods also called livelihood planning has been described as one of the most important socio-economic drivers for reforestation success by Le *et al.*, (2012). This strategy reduces the degree of dependence on traditional forest products by providing alternatives for the locals.

A third factor that was responsible for the success of the *market square* tree planting project was the personalization of task. In the *market square* tree planting project, personalization of task involved assigning different planters the tasks of watering, removal of weeds and the general survival of the trees. This increased the survival rate of the trees. It has also been argued that adequate determination of the roles of the different stakeholders from the onset of the tree planting project is a fundamental key to success (Wylie and Johnston, 1984; Close and Davidson, 2002; Dudley *et al.*, 2005). This places stakeholders in a better position of knowing exactly what they are expected to do. In fact, the results of a survey carried out in Ethiopia on tree planting showed that 93.1% of the respondents favored private ownership of trees and forests in the midst of wide deforestation. The argument of course here is that with such ownership it is easier to be accountable and to take care of the trees (Urgessa, 2003). However, Harrison *et al.*, (2008) observed that a synergy between public and private

stakeholders is often very important especially when it comes to seedlings production.

Another success factor is adequate training of planters. Training may include the development of the skills of the planters such as associating planting with adequate watering, post-planting removal of weeds, use of treeguards and the methods of planting such as making sure the seedlings are planted without exposure of their root balls to avoid desiccation. Most tree planting success stories in Tasmanian, China, New England, SSA and most of Asia are linked to such best practices (Mackay, 1978; Wylie and Johnston, 1984; Potter, 1988; Higgins *et al.*, 1989; Kirkpatrick *et al.*, 2000; Zhang *et al.*, 2002). In the case of the *market square* tree planting project, the planters were properly skilled and this was seen as they were involved in good practices such as the use of treeguards for young trees and thereby protecting them from being eaten by cattle, removal of weeds to avoid competition for nutrients and timely planting of the trees just before periods of heavy rainfall (April) which reduced the issue of water logging and scarcity. In general, the technical capabilities that could be acquired through training of the stakeholders affect the sustainability of the project in both the short and long term. In the Philippines, it was found that NGOs needed more technical training to effectively manage reforestation projects (Chokkalingam *et al.*, 2006).

The results of the *outdoor mosque* tree planting project are also consistent with several other published results (Mackay, 1978; Spears, 1983; Moon and Park, 2004). Limited stakeholder participation was the main reason why the project failed. The main stakeholders that were implicated in this project were the Secretary General, the Divisional Officer of Garoua, the Mayor, the Divisional Delegate for Environment and Forests, the Lamido, the indigenes, local nursery man and the Peace Corps Volunteer. According to FGD and interviews with key informants, the main participation loop was seen as the Lamido failed to ask his people to weed the area in time and to help in properly protecting the planted trees. The indigenes did not take

the project seriously because they were seriously involved in planting crops on their own farms. By the time the trees were planted the rains were almost running out. This eventually made the planting to be done when the rains were running out and exposed the trees to the sun and cattle. The authors of these studies (e.g. Mackay, 1978; Spears, 1983; Moon and Park, 2004; Dudley *et al.*, 2005) argue that limited participation of some facets of the population is likely to create major problems in any tree planting project because, those who do not participate may not be able to appreciate the efforts and value of what has been done and may be ignorantly helpless in the case of trying to protect such reforested areas. Several restoration programs have failed because the locals are not often asked to say what they really want (Dudley *et al.*, 2005).

Another reason for the failure of the *outdoor mosque* project was the lack of diversification of livelihood activities. This is because the project lacked any mechanisms put in place to stop the people from cutting trees for fuel wood and rearing their animals on the trees. No matter how the project is structured, if the population depends on the forest for subsistence and the stakeholders of the project do not judge how the population can be provided other options of subsistence; the project is likely to fail. This has been very noticeable in the Philippines, China, Malawi, India and West Bengal where the differences in tree planting project survival have been varied for the same reasons (Spears, 1983; Lamb and Gilmour, 2003).

The *outdoor mosque* project also failed due to water scarcity issues. Just as water is of great importance to humans, it is also very vital to plants. It has been confirmed that watering of plants after planting is a vital practice for their survival. In the same way, scarcity of water may cause the plants to end up being desiccated as has been the case in many parts of Tasmania (Mackay, 1978; Mackay *et al.*, 1984; Kirkpatrick *et al.*, 2000). Elster, (2000) also argue that tree planting failures in Colombia have been associated to water shortages.

Leadership problems were also responsible for the failure of the *outdoor mosque* project. Spears, (1983) and Le *et al.*, (2012) argue that this is a major source of failure in most tree planting projects as some stakeholders are either in conflict with one another or do not seem to agree on the way forward. In the case of the *outdoor mosque* project, there was a leadership problem as the Lamido was unable to order his subjects to protect the trees, remove the weeds on time to prepare the landscape for planting and the planting was done towards the end of the rainy season (October-November, 2001). Conflict of interest between the Mayor and the Delegate for Environment and forests on the source of finances to set up the nursery was also a concern.

As concerns the judgment of the meaning of success and failure, this study holds that the number of trees that grew to maturity or attained harvest age is the main issue of concern. Spears (1983) notes that a major way of telling if a tree planting project is successful is by knowing if the trees planted grew to maturity, and all other indicators are within this. This view has also been supported by Gunter *et al.*, (2009) as they argue that in the Andes early height development of native species is an indicator of successful plant growth. Other studies that argue that success in tree planting can be judged from whether the trees have grown to maturity or attained harvest age are (Lamb and Gilmour, 2003; Chokkalingam *et al.*, 2006; Nawir *et al.*, 2007; Kanowski *et al.*, 2008).

6.9. CONCLUSION

It has been demonstrated that some management practices result in more successful tree planting projects than others. The overriding conclusion that can be drawn from the success story presented in this study is that where there is a strong tradition of community oriented participation that brings all stakeholders together, success is likely to come by. Also, the diversification of livelihoods and training of planters support project success. To most respondents, success can be judged when trees reach

their production stage or attain harvest age. The focus on the socio-economic variables that determine success is guided by the fact that they are considered more important than the biophysical drivers (Walters, 1997). The logic of this argument is that once the socio-economic factors are well managed, the biophysical or ecological factors will also be properly sustained as man remains at the center success. If environmental or biophysical factors were the main drivers then the same results would have been obtained for both projects. It has been argued that socio-economic and technical factors play a more important role in the outcome of any tree planting project (Crk *et al.*, 2009; Le *et al.*, 2012). This is because even if the soils are good and there is sufficient water for the trees, inadequate management such as removal of weeds, using of tree guards and proper training of planters would ultimately cause the project to fail. In the case of the projects involved in this study, the environmental conditions were almost the same as rainfall was the same and compost was used in growing the seedlings to enhance survival even during the initial years after outplanting. The moisture limiting option was handled in the market area through regular watering and weeds removal. All these factors including participation and diversification of livelihoods played an important role.

The elements of success in tree planting are inter-connected and a holistic approach that brings all the factors into consideration is suggested. This means that to better understand the problem, it is relevant to look at several variables and analyse the overall picture. The policy implications of this study are that local realities or population perceptions should be taken into consideration when planning and executing reforestation projects in the midst of environmental factors.

Further research should be conducted by testing these results on larger tree planting projects, studies integrating biophysical factors from an environmental point of view should be conducted, and studies that assess tree growth parameters such as heights and diameters are encouraged. Also, funding should be made available to explore this rather virgin aspect of African human ecology. More evaluation studies on other

reforestation projects in both the arid tropical grasslands and humid rainforest should also be carried out in Cameroon. Also, as Harrison *et al.* (2008) argue that an evaluation of the seedling production process should also be carried out and a major shift from the government focused strategy of producing large quantities of seedlings at the expense of quality should be further verified.

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CHAPTER VII

POLICY OPTIONS TOWARDS DEFORESTATION REDUCTION IN CAMEROON: AN ANALYSIS BASED ON A SYSTEMATIC APPROACH

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7.1. RÉSUMÉ

Cette étude vise à faire ressortir avec les mesures principales qui peuvent être utilisées pour combattre le déboisement au Cameroun basé sur les causes principales de déboisement. De plus une attention particulière est accordée aux possible réductions d'émissions de CO₂ et les effets sur le produit intérieur brut (PIB) et les emplois basé sur différents scénarios de réduction de déboisement. L'étude utilise une approche systématique pour analyser les causes, les agents, l'analyse spatiale et les politiques de réduction du déboisement. Les résultats montrent que l'intensification de la production agricole constitue le meilleur moyen de réduire le déboisement. D'autres politiques au sein de la REDD + et la collaboration internationale, la distribution des quotas, et la stricte émission des permis entre autres sont également importantes.

7.2. ABSTRACT

This study advances measures that can combat deforestation in Cameroon. It also looks at possible carbon dioxide (CO₂) emission reductions and the effects on gross domestic product (GDP) and employment based on selected baseline reductions in deforestation. A systematic approach of analyzing the drivers, agents, socio-economic context, political context, spatial context of deforestation and specific and general deforestation reduction policies is used. The final step of the approach is to verify the repercussions of deforestation reduction on CO₂ emissions, employment and GDP. Monitoring population growth and arable production through intensification of production is promising. The general policies that this study postulates are enforcement, legal adherence, specification of tasks and quotas, collaboration, forest licensing and monitoring. More specific policies could be within the reduction of emissions from deforestation and forest degradation mechanism (REDD+) as well as diversification of livelihoods, mechanization, use of organic fertilizers and intensive cattle farming inter alia. Reductions in deforestation will reduce atmospheric CO₂, employment in the forestry sector and the share of forestry's contribution to GDP.

Keywords: deforestation, population, agriculture, REDD+, policies, systematic approach, intensification of farming, quotas, Cameroon

7.3. INTRODUCTION

Presently, about 20% of our global anthropogenic carbon dioxide (CO₂) emissions are as a result of high rates of loss of tropical forests (Muller *et al.*, 2013; IPCC, 2007). Other repercussions of the loss of forests globally and in Cameroon in particular are loss of biodiversity, destruction and disruption of hydrological processes and reductions in food yields inter alia (Epule *et al.*, 2012a). Cameroon's forests constitute part of the Congo Basin which is the second largest tropical rainforest hot spot in the world after the Amazon Basin in Latin America (Epule *et al.*, 2011). For example, the forests in Cameroon are said to contain close to 2,696 million metric tons of carbon in living biomass (FAO, 2010a). This makes the loss of forests even more daunting for the environment. In addition, Cameroon had about 28 (Mha) of forests as of the year 2000 and of this number, about 220 (Kha) were lost each year during the decade 1990-2000; this is equivalent to about -1.0% of annual forest cover loss (Food and Agricultural Organization (FAO), 2010 a, b).

It has been argued that reducing deforestation is one of the most cost effective ways of reducing greenhouse gases (Eliasch, 2008). In Cameroon, forests are very important to the population because they provide about 80% subsistence to most rural communities that fetch fuel wood, hunt animals, farm, gather non-timber forest products (NTFP) and breed animals (FAO, 2007; Ministry of Economy and Finance (MINEFI), 2002). The annual economic value of forest products such as veneers saw wood, timber, pulp and parquets can be valued at millions of dollars while the forest sector's contribution to the country's gross domestic product (GDP) is in the range of 6-10% (CBFP, 2006; MINEFI, 2006; Alemagi and Kozak, 2010).

Currently, the United Nations Framework Convention on Climate Change (UNFCCC) has negotiated a financial mechanism that supports developing countries in their attempt to reduce emissions from deforestation under the scheme called reduction of emissions from deforestation and forest degradation (REDD+). The

scope of the extended REDD+ will be based on activities such as sustainable management of forests, protection and enhancement of carbon stocks, conservation, formulation of national REDD+ strategies, capacity building, implementation of policies for the national REDD+ programs and quantification of changes in emissions (Dkamela, 2011). However, following the failure of UNFCCC in Copenhagen Denmark in 2009 to arrive at a final version of the REDD+ mechanism at a global level, doubts still exist with respect to the specifications of the mechanism and concrete blueprints on the ground. Because of this lack of clarification, the analysis of how REDD+ will be received in Cameroon is still unclear and warrants analysis (Dkamela, 2011).

REDD+ holds plenty of promise for Cameroon based on pilot studies carried out in Nkolenyeng (Cerutti and Lescuyer, 2011; Neale *et al.*, 2010). Here, the Association des Femmes et des Hommes Amis de Nkolenyeng (AFHAN) and a national non-governmental organization (NGO) have begun the first pilot forest conservation program aimed at reducing deforestation in the community forest area and thereby reducing emissions from deforestation and forest degradation (Lescuyer, 2010). This is based on the fact that there has been a lack of effective action to ensure the involvement of the indigenous people and forest communities. Furthermore, even with the submission of the readiness plan idea note by the government of Cameroon in 2008, the country's readiness planning linked to the forest carbon partnership has not involved the indigenous people who remain major stakeholders (Dkamela, 2011; Brockhaus *et al.*, 2012). However, according to REDD+ Partnership (2011), Cameroon is already scheduled to benefit about \$10.66 million between 2010 and 2014 for all its efforts at reducing deforestation and forest degradation. The main donors here are the global environment facility, Japan (providing the bulk) and the forest carbon partnership facility under the auspices of the other 'partner countries' category (UN-REDD, 2013).

In this study, deforestation is not only limited to the view point of the FAO which looks at the phenomenon as a loss in the number of trees but also from the view point of the United Nations Research Institute for Social Development (UNRISD) that considers it to be forest degradation in the context of reduced quality of the trees in terms of their density, structure, ecological services, species diversity, and impoverishment of standing wood quality. Therefore, this study will define deforestation in the context of REDD+ to be a reduction in the number and quality of trees over varied spatial dimensions due to anthropogenic and natural drivers.

Conceptually, it can be noticed that when population increases there is an increase in the demand for food, meat or more generally protein and fuel wood which can easily be obtained from cattle, forest products, increase logging inter alia. This in turn leads to an increase in cattle stock, logging, and extraction of forest products and the cultivation of more land to meet food needs. All these land uses are to the detriment of forests since they all lead to reduced forest area (Figure 7. 1.).

It is therefore important to assess the effectiveness and efficiency of policies aimed at curbing deforestation. One way of doing this is by carrying out detailed country specific studies that examine the causes of deforestation and base the policies to overcome deforestation on these causes or drivers (Muller *et al.*, 2013). The processes, patterns, causes and agents of deforestation vary from region to region and from country to country as different political, economic and spatial circumstances exist (Fearnside, 2008). This necessitates the use of a systematic approach to analyse the actual causes of deforestation and possible policies to reduce deforestation at a national scale.

The first objective of this study is to identify the drivers of deforestation in Cameroon, the spatial context, political context and the socio-economic context of deforestation. The second objective looks at the general and specific policies that can be used to curb deforestation in Cameroon. This is followed by an analysis of the

impact of various deforestation reduction scenarios on gross domestic product (GDP), employment and CO₂ emissions in Cameroon and related policies. To the best of our knowledge, this is the first study that applies the systematic approach in postulating deforestation reduction policies in Cameroon. The overall objective of this study is to present specific policies that can combat deforestation in Cameroon based on the key drivers of deforestation, the politico, socio-economic and spatial contexts of deforestation. In the sections that follow, this study will present the systematic approach, the main drivers of deforestation in Cameroon, the political, socio-economic and spatial context of deforestation in Cameroon. This will be followed by an analysis of the general and specific policies that can be used to curb deforestation in Cameroon. Finally, the study presents three deforestation reduction scenarios and their effects on GDP and employment and ways of managing the situation.

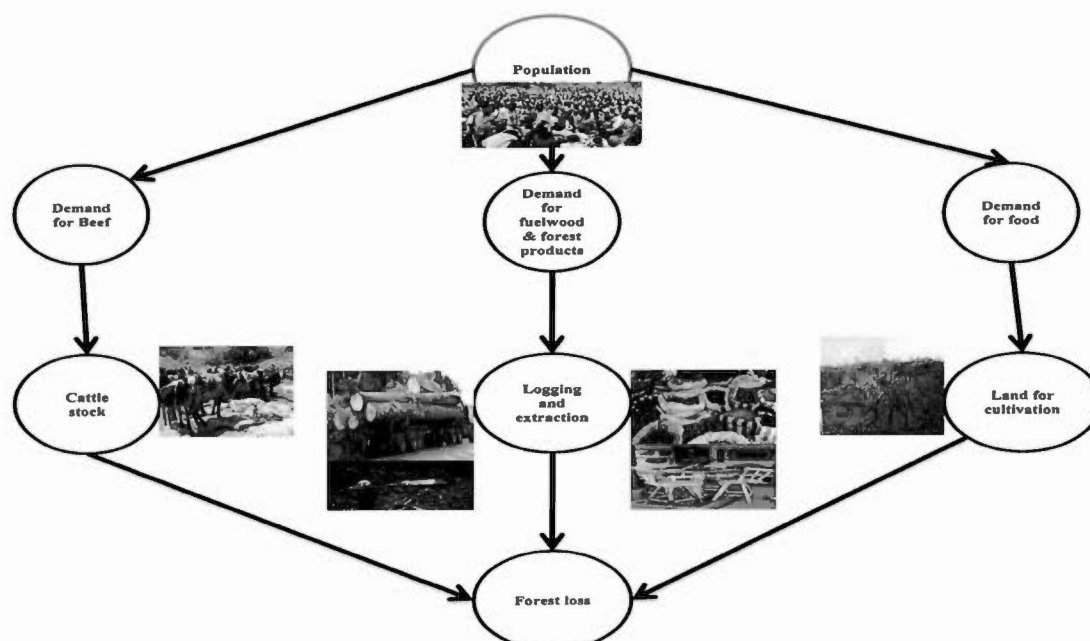


Figure 7.1. Conceptual framework of the linkages between population, arable land, cattle stock and logging/extraction of forest products.

7.4. THE SYSTEMATIC APPROACH

The examination of the key drivers and agents responsible for deforestation is based on the applications of the systematic approach (Figure 7.2.). All the phases of this approach were first used by Muller *et al.*, (2013) and this current study is perhaps to the best of our knowledge the first to apply the approach in Africa in general and Cameroon in particular. Because different drivers are responsible for deforestation in different countries, the strategies used to reduce deforestation have to consider the differences in the drivers and their resultant land uses. The problem with existing research is that deforestation reduction policies have been based on trying to “copy and paste” solutions that have worked in other areas without consideration of spatial variations. In the steps outlined below, the drivers are linked to the spatial distribution of the land uses in order to identify relevant policy options. The steps outlined in this approach are as follows:

Step one: This is mainly concerned with the identification of the key drivers of deforestation in Cameroon. To be more specific, the key drivers of deforestation in Cameroon are: population, arable and permanent cropland, arable production, rainfall, trade in forest products/logging, fetching of fuel wood and cattle stock (Epule *et al.*, 2011; Allen and Barnes, 1985). For this analysis, the drivers shall be reclassified as follows: 1. population and arable and permanent cropland 2. Trade in forest products 3. fetching of fuel wood, and finally 4. cattle stock. The reason for reclassifying these categories is to bring together variables that are closely linked and self-reinforcing and whose agents are similar. Allowing as stand-alone variables does not bring in anything new into the study. The categorization used here applies to most situations of deforestation in Africa and these variables are the most important in the case of Cameroon. Other factors such as rainfall declines and rise in temperatures, insect pests, fires, soils *inter alia* are either less relevant due to their low impacts on forests and due to the absence of reliable data (Kirby *et al.*, 2006).

Step two: Here, emphasis is mainly on the analysis of the political context of environmental and forest management in Cameroon. A historical analysis of the various politico-administrative organs that govern forests in Cameroon is carried out. The weaknesses of these agencies are brought to light. The various governmental, non-governmental and international organizations that have had a role to play are systematically analyzed.

Step three: This phase is based on a socioeconomic analysis of the different drivers of deforestation. It touches upon the keys agents, locations, main products, methods of production and markets of the products of the key drivers of deforestation in Cameroon (Table 7.1). This touches upon some aspects of step four which is based on the spatial context of the drivers. Also, an economic analysis of the effects of deforestation reduction on forestry's contribution to GDP and employment will be carried out (see step seven of the systematic approach).

Step four: However, with the spatial analysis, land use maps are used to show where each of the key drivers is dominant. In summary, the key issues in the spatial analysis phase are: (1) mapping and locating the proximate drivers of deforestation; (2) quantification of their impacts in the past. Steps five and six are focused on analyzing general and specific measures that can be used to reduce the key drivers of deforestation respectively. These measures are based on the key drivers.

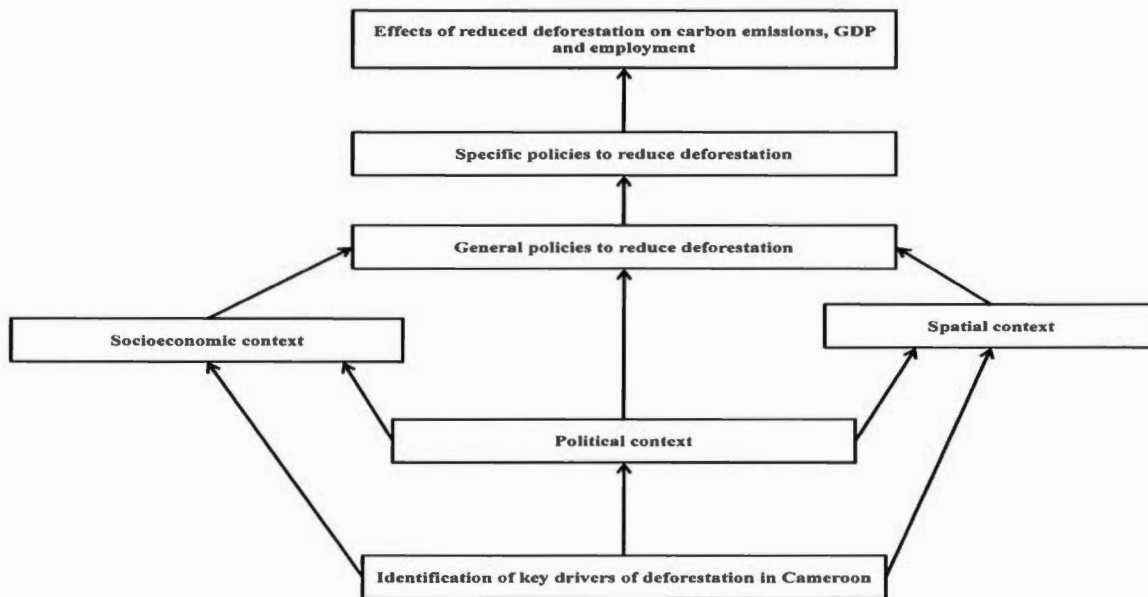


Figure 7.2. Schematic view of the systematic approach aimed at reducing deforestation.

Source: Modified from Muller *et al.*, (2013).

Step seven: Within the context of the policies aimed at reducing deforestation, an analysis of the effects of such action on carbon dynamics and GDP is carried out. To examine the effects of reduced deforestation on CO₂ emissions, GDP and employment opportunities; data on the annual forest area loss of 220 Kha and CO₂ emissions per hectare of 462t were obtained from FAO, (2010a, b). The GDP and related employment levels associated with the 220 Kha loss of forest were set at 10% and between 45000 to 70000 respectively (Alemagi and Kozak, 2010; Amariei, 2005; CBFP, 2006). The following deforestation reduction scenarios were set:

Scenario one: Business as usual (BAU) (i.e. maintaining the current 220 Kha of annual forest area loss) and a parallel forestry employment level of between 45000-70000 and 10% contribution to GDP which served as the basis for the development of all other scenarios. Scenario two: a 25% reduction in deforestation; Scenario three: a

50% reduction in deforestation. Scenario four: a 75% reduction in deforestation. To compute the annual amount of CO₂ emissions based on the amount of forest area lost, the following equation was used.

$$\text{CEMF} = \text{AFAL} \times \text{CEMFH}$$

Where, CEMF is annual CO₂ emissions from forests, AFAL is annual forest area lost (220 Kha) and CEMFH is CO₂ emissions from one hectare of forest lost (462t). The appropriate GDP and employment changes were also calculated based on the scenarios above.

7.5. RESULTS

7.5.1. Key drivers of deforestation in Cameroon

In the context of Cameroon, the key proximate causes of deforestation in order of importance are population, arable and permanent crop land, arable production, rainfall, trade in forest products/logging, fetching of fuel wood and cattle stock (Epule *et al.*, 2011; Allen and Barnes, 1985). In a related regionally focused study, Mbatu, (2010) observes that the expansion of agricultural land and urban population growth are the key drivers of deforestation in Cameroon. However, the three most significant drivers are population, arable and permanent crop land and arable production as categorized by Epule *et al.*, (2011). These categories were obtained based on a multiple linear regression model that was fitted to all the variables named earlier with forest area loss being the dependent variable (Epule *et al.*, 2011). Because these categories are self reinforcing; this study shall reclassify them based on their closest land use taxonomy and multi-collinearity. In this regard, this analysis shall be based on the following optimized categories of drivers of deforestation: population and arable and permanent cropland, trade in forests products/logging and fetching/gathering of fuel wood and finally cattle stock. It is worthy of note that this shows that there are lots of internal variations in the factors that cause deforestation as one moves from one region to another. In Bolivia for example, the proximate

drivers of deforestation are different from those in Cameroon. In a study by Muller *et al.*, (2013), the proximate causes in order of importance are mechanized agriculture, small scale agriculture and cattle ranching.

7.5.2. Political context shaping deforestation/forest management in Cameroon

With an annual rate of deforestation of about 1.0% and 220 Kha of forests lost annually (FAO, 2010a, b), some efforts at the level of the national and international forest governance aimed at curbing forest loss are worthy of being analyzed. Environmental regulations in Cameroon are relatively new, dating back to the last two decades. During the era of colonization and the early years of independence there was a body of laws governing the use of natural resources. However, the real pace setter into concrete environmental regulations was in the 1990s. As such, in 1992, the Cameroon government created the Ministry of the Environment and Forestry (MINEF) with an objective of implementing the Cameroon government's environmental commitments. This was done in preparation of the 1992 United Nations conference on Environment and Development (UNCED) in Rio de Janeiro Brazil (Greiber and Schiele, 2011). In 1994, a forestry law was passed that defined forests not as an ecosystem but rather a sector made of forest products to be exploited for profit motives. The 1994 forestry law argues that forest management includes sustainable production of forest products and services without compromising future productivity of the forests (Greiber and Schiele, 2011).

In 1996, the environmental framework law was created. This law is the 'cornerstone' of environmental regulation and it led to the National Environmental Management Plan (NEMP) and a forest Environment sector program (FESP) with views on the meaning of forests not very different from the 1994 forestry law (Greiber and Schiele, 2011). The 1996 constitution of Cameroon however adopted a Brundtland or ambivalence approach to resource management with emphasis on sustainable

exploitation, protection and ensuring a healthy environment and ensuring environmental protection as a right to all citizens (Greiber and Schiele, 2011).

In December 2004, MINEF was split into the Ministry of Forestry and Wildlife (MINFOF) and the Ministry of Environment and Nature Protection (MINEP). MINFOF supervises the government's forest policy through an agency called the National Agency for Forest Development (ANAFOR) which plans and supervises tree planting by communities, municipalities and private companies (Greiber and Schiele, 2011). The livestock sector is controlled by the ministry of livestock, fisheries and animal industries (Greiber and Schiele, 2011).

In the area of international forest governance, Cameroon has been involved in the REDD process through a pilot project in 2007 (Brown *et al.*, 2011). The project had as objectives the establishment of baseline projections of emission reduction from deforestation. However, it can be observed that because of a lack of clarification on the way forward for REDD+ in terms of the involvement of local forest community stakeholders, it is still unclear how REDD+ will be received in Cameroon (Dkamela, 2011; UNFCCC, 2011). However, Cameroon had earlier ratified the Kyoto protocol and is also a member of the UNFCCC (Purdon, 2005; UN-REDD, 2011).

In spite of this plethora of forestry laws, not much has been achieved in curbing forest loss. This is because of the following reasons: Firstly, there is a framework of legal pluralism in which there is co-existence of customary and statutory laws which are legacies of the German, British and French legal systems (Greiber and Schiele, 2011). Also, with the proliferation of several ministries, one depicts a set up of overlapping competences in which several ministries with similar functions do exist and everyone expects someone to take action and finally no action is taken. To make things worse, the country's forest management has been affected by red tapism or too much official formalities, bureaucracy, nepotism and corruption which undermine attempts at the regulation of the forest sector especially in the area of issuing of logging licenses,

illegal logging and the punishment of non-compliance (Alemagi and Kozak, 2010). The ministries depend on foreign aid for 75% of their budget. Following the signing of the structural adjustment program with the Bretton woods institutions, most of these ministries suffered budgetary cuts imposed by the government due to the economic crisis. This hampered the ability of these ministries to fully implement what one would call good laws that are gathering dust on bureaucratic shelves in offices (Greiber and Schiele, 2011).

7.5.3. The Socio-Economic context of the key drivers shaping deforestation in Cameroon

This section reviews the socio-economic dimensions of the three categories of key proximate causes of deforestation in Cameroon which are population and arable and permanent cropland, trade in forest products/logging and fuel wood and cattle stock (Table 7.1). It is important to note that due to these socio-economic pressures, the need for more land is created and consequently there is more deforestation. For details on this see paragraphs that follow.

7.5.3.1. Population, arable and permanent cropland

Population and arable production and permanent cropland are two of the key causes of deforestation that are closely linked and mutually reinforcing to each other. Cameroon has a population of about 20.03 million people. This has been based on an increase from a population of 5 million people in 1961. The current rate of growth of the population is about 2.08 % per year on average (Table 7.1) (Mundex Dataset, 2012; Central Intelligence Agency, 2012; Carr and Suter, 2006).

Table 7.1. Agents, location, main products and methods of production of main causes of deforestation in Cameroon

	Population, arable production & permanent cropland	Trade in forest products & fuelwood fetching	Cattle stock
1-Agents	14-16 million small holders	National & foreign companies, local populations	Small & large scale holders, government
2-Location	7160 hectares allover the country	Tropical forest region	Mainly in the North
3-Main products	Beans, maize, plantains, cocoyams, banana, groundnuts etc	Timber, pulp, forage, lumber, fuelwood etc	Meat, dairy products
4-Production	Shifting cultivation, slash & burn cultivation, based on manual labour	Mechanized & large scale, manual and small scale	Extensive nomadic herding, ranching
5-Markets	Locally & excess sold within the central African region, little exports	Locally & internationally	Locally, nationally, little exports

Arable production in Cameroon involves about 14-16 million Cameroonians. Almost 7160 ha of land are involved in this category and it is carried out all over the country. Some of the crops cultivated are beans, rice, maize, plantains etc (FAO, 2010a, b). These crops are cultivated mostly through shifting cultivation, slash and burn cultivation and the use of human labour (FAO, 2010a, b). The main markets for the excess outputs are in the big cities and other Central African countries. The issue here is that this population is a dominant pressure behind the need for more land to carry out arable farming. In fact, agriculture employs about 70-80% of the Cameroonian population, accounts for more than 50% of exports and about 30% GDP (DSCN,

2002; Shackleton *et al.*, 2007). Population and permanent cropland are the first and second major causes of deforestation in Cameroon. This has been verified through empirical analysis of several drivers in which a linear regression model was fitted (Epule *et al.*, 2011). This is true as population growth triggers a higher demand for cropland leading to loss of forests.

7.5.3.2 Trade in forest products/logging and fuel wood

Trade in forest products/logging and fetching/gathering of fuel wood is another cause of deforestation in Cameroon. It is carried out by national and foreign timber exploitation companies and the local population. The economically viable part of this extraction is essentially taking place in the south dominated by tropical rainforest (Alemagi and Kozak, 2010). The north is essentially grassland but however one can find a mix of drought resistant trees and grass. Tree planting in the north has become an urgent issue being that this eco-region is fragile and threatened. The main products here are timber, paper and pulp, lumber and fuel wood *inter alia* (Mertens *et al.*, 2001). Extraction is mainly based on mechanization while the exploitation of fuel wood is still essentially manual but in some cases semi mechanized through the use of chain saws. The key markets here are mostly local and international. For example, extracts from the bark of a tree called *Pausinystalia yohimbe* are consumed locally as they cure several ailments and are also sold in Europe and North America (Sunderland *et al.*, 2002). Fuel wood is mostly consumed nationally while timber, pulp etc are consumed both nationally and internationally. Forests and forest products play a vital role in the economy of Cameroon by accounting for close to 10% of the GDP and providing between 45000-70000 jobs (Alemagi and Kozak, 2010; Amariei, 2005). As the 6th main exporter of tropical wood in the world, the trade in forests and forest products enhanced Cameroon's export base by 19% between 1990 and 2000 or about US\$ 60 million each year (Lebedys, 2004; Nguemdjom, 2006). Fuel wood on the other hand is a major source of energy/fuel and income in many small

communities where there is a limited potential for other sources of energy/fuel (FAO, 1998).

7.5.3.3 Cattle stock

Cattle stock on the other hand is carried out by either large or small scale holders. This is often in the form of agents with either a large number of cattle that move around extensively in search of pasture or stay in paddocks. The government has also been involved in this sector with a prime motive of improving research in the cattle sector especially when it comes to cross breeding to enhance production. Cattle breeding accounts for about 16% of agricultural production (Tambi, 1991; Kameni *et al.*, 2007). Cattle breeding is mainly carried out in the Far North region, the North region, the Adamawa region and the North West region. In fact, 90% of all the cattle raised in Cameroon come from great agglomerations such as Maroua, Garoua, Ngoundere and Bamenda. Much of the resultant meat and dairy products are transported to the south of the country to meet up with the urban demand for meat in cities like Douala, Yaoundé, and Kumba inter alia (Kameni *et al.*, 2007). The key methods of production here are either open range nomadic herding which is extensively destructive to forests and grasslands or ranching (Muller *et al.*, 2013; Gautier *et al.*, 2005). This sector has not been fully developed into a full export sector beyond the central African sub-region for some reasons. Trade restrictions, fears of transportation of diseases such as foot and mouth disease and a low output efficiency and competitiveness of Cameroonian meat and dairy products abroad are among the bulwarks (Merry *et al.*, 2002).

7.5.4. Spatial analysis of the key drivers of deforestation in Cameroon

Here, this study offers a spatial analysis of the key drivers of deforestation in Cameroon. This goes a long way in showing the geographical spread and distribution of the key drivers. Cameroon is endowed with a myriad of vegetation types. In the south, the country has mainly tropical forests that are made up of the dominant tropical rain forests and the Mangrove forests that are common around the swamps of

most wetlands. The northern part of the country is dominated by essentially tropical grasslands mixed with some arid trees. In the Adamawa region we can find Guinea and Sudan Savanna vegetation while in the north we have Sudan Savanna and in the extreme north region we have essentially Sudan Savanna and Sahel Savanna (Figure 7.2a) (WRI, 2012). Generally, trade in forest products and non-timber forest products takes place in the tropical rainforest region of the south. Fetching of fuel wood is a common activity in this same region being that a good proportion of the population depends on this as a source of fuel and income (FAO, 2010a, b).

In terms of population, it can be observed that the most densely populated areas are distributed all over the country due to the presence of diverse poles of attraction such as large cities, water resources, forest resources, means of transportation, fertile agricultural lands and security. In the northern part of the country, the key concentrations are in the north, extreme north and Adamawa regions and around agglomerations like Maroua, Garoua, Kousseri and Ngoundere which all have population densities of close to 250 persons per Km^2 with Cameroon having an average population density of about 40 persons per Km^2 (Figure 7.3b). These huge populations are mainly involved in nomadic cattle herding which has negative devastating impacts on the vegetation. The other regions have densities of between 100 and 250 Km^2 (FAO, 2010a, b). In the South, densities of 250 Km^2 can also be found in and around large cities like Yaoundé, Douala, Bamenda, Bafoussam and Bertoua inter alia. The western highlands extending to the coast also has densities of between 100-250 Km^2 (Figure 7.3b) (Mundex Dataset, 2012). Generally, for both the north and south, there is very little area with densities above 1000 Km^2 as seen on Figure 7.3b.

Arable production in Cameroon is equally variable between the north and the south of the country. Generally, in the south, the key crops grown are crops such as plantains, coco yams, cassava, potatoes, vegetables and generally tubers while in the north most of the arable farmers are essentially involved in the production of cereals such as

groundnuts, beans, maize, rice, sorghum to name but a few. However, it is possible to find both cereals and tubers grown generally all over the country (Figure 7.3c) (DSCN, 2002; Shackleton *et al.*, 2007). In the area of cattle stock herding, the northern regions are more adapted. The western highlands, the Adamawa, the north and extreme north are essentially the dominant eco-regions for livestock farming due to their extensive rangelands made of grass (Fig.3d) (Kameni *et al.*, 2007).

Generally, the areas of dense population are equally the areas where high rates of deforestation have been recorded all through the country. These same regions are either areas of arable farming in the south or cattle herding in the north.

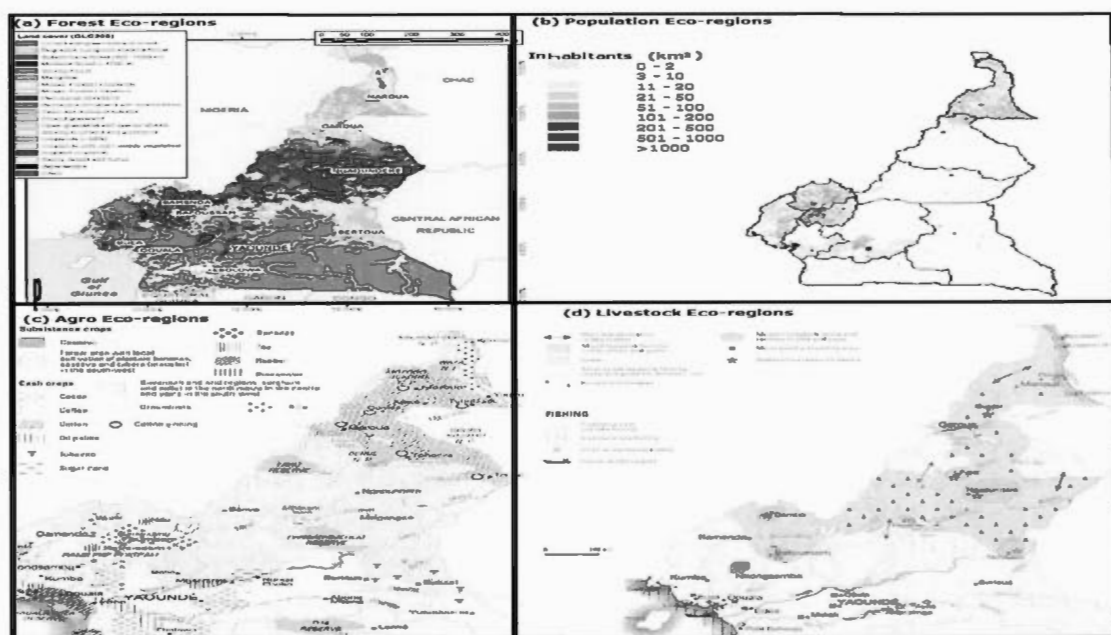


Figure 7.3. Location of (a) Forest eco-regions, (b) Population eco-regions, (c) Agro-eco-regions, and (d) Livestock eco-regions in Cameroon.

Source: Modified from: <http://www.wri.org/map/>, <http://www.bestcountryreports.com/> and <http://www.fao.org/ag/>.

7.6. DISCUSSION

7.6.1. Policy measures to combat deforestation based on the specific context of key causes

In this section, this paper attempts at identifying some general and specific measures that could be used to reduce deforestation in Cameroon. Generally, it has been often said that Cameroon has some of the best environmental protection laws in sub-Saharan Africa; yet, implementation has been a major bulwark. Generally, one area where work has to be done is the strengthening of capacities of the various agencies and ministerial departments responsible for forest management. The first phase here will involve avoiding overlapping competences with regards to who does what. This will mean the tasks of the different stakeholders will be clearly specified such that each agency knows exactly what its role is in environmental management. There should be a specific department in charge of forests and not several departments to avoid overlapping competence. Furthermore, there should be effective and efficient collaboration and capacity building at the national, provincial, divisional, sub-divisional and municipal levels. This will however not be effective if corruption and illegal lumbering are not dealt with. This therefore calls for developed countries to cut down their desire for illegal/uncertified tropical timber. International organizations should equally launch a fight against uncertified timber from Cameroon (Mbatu, 2010).

Also, penalties that are deterring should be placed on all those who do not comply with the forest protection laws. Furthermore, like in other parts of Africa and Brazil, the Cameroon government should set a specific deforestation reduction target under the auspices of REDD+ (Nepstad *et al.*, 2009; Christophersen and Stahl, 2011; Phelps *et al.*, 2012). However, a REDD+ stakeholder participation platform which involves all stakeholders especially the local forest communities should be taken into consideration and should be based on a bottom up approach in which the indigenes at the 'grass root level' are given priority (Gunilla *et al.*, 2013). This view point is

supported by the fact that the process of getting countries involved in REDD+ establishes and involves the role of states, institutions and other high level stakeholders and poses a risk of ignoring the participation of the indigenes or local communities (Beymer-Farris and Bassett, 2012; Gunilla *et al.*, 2013). As reported by Dkamela, (2011), this is a major flaw that hampers Cameroon's readiness for REDD+. In fact, the relationship depicted in the general measures outlined here show a network of drivers interacting and ranging from specification of tasks, collaboration, setting of quotas, forestry licensing, monitoring, enforcement and legal adherence (Figure 7.4.). More specifically, the section below will now address the key measures that can reduce deforestation based on the key causes of deforestation (Figure 7.5.).

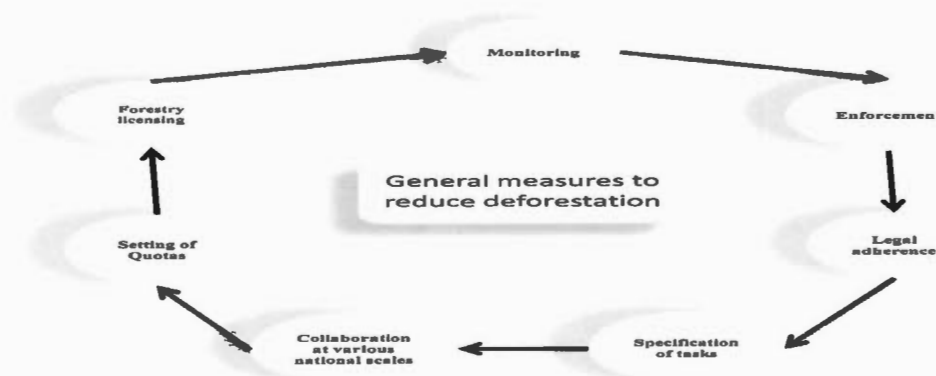


Figure 7.4. General measures to combat deforestation.

7.6.1.1. Population, arable and permanent cropland

To be able to reduce deforestation ensuing from this key cause of deforestation at a national scale in Cameroon, a shift in the current systems of farming has to be adopted. Primarily, these problems anchor on the fact that increased population enhances demand for arable land in the midst of low agricultural technology. As the most dominant factor, it will be necessary to stabilize the expansion of farm sizes by

adopting intensive methods of cultivation. The intensification of land uses in Sumatra, Indonesia has been used as one means of reducing deforestation and the results have been positive (Tomich *et al.*, 2001). This calls for the use of sustainable organic fertilizers, machines and generally high yielding varieties that will increase production at the present farm sizes (Epule *et al.*, 2012b).

However, for this to be feasible, a common synergy of actors has to be put in place. This will entail commitments from the government and the farmers. On its part, the government will have to make the farm inputs available to the farmers at low interest rates while the farmers will have to use the inputs efficiently so that they can pay back the loans from their sales and have extra for their subsistence. Through the World Bank and the African development Bank, additional financial mechanisms (similar to REDD+) that compensate farmers who decide to reduce deforestation by not expanding their farms and rangelands as is currently the case with REDD+ participants would be good. Adopting agroforestry techniques of incorporating trees in to farms will also enhance management. In Latin America, this has already been very visible as the Brazilian Development Bank has compensated farmers who have decided to protect the rainforest instead of expanding farms (Figure 7.5.) (Tollefson, 2009).

Since its establishment in 2008, the REDD+ program has benefited from donations from countries like Norway, Denmark, Japan, the European Union, Spain, the Grand Duchy of Luxembourg inter alia (UN-REDD, 2013). For the year 2013, Norway for example has deposited \$34.8 million. Norway's contributions now total 141.2 million. In addition, the European Union and Luxembourg have recently signed donor agreements totaling \$15.6 million. In January 2013, Denmark pledged \$1.8 million adding to its previous contribution of \$8 million between 2009 and 2012. Spain also increased its contribution in 2012 by \$648.000 bringing its total contribution this far to \$2 million. The contribution of Japan remains at more than \$ 3

million (UN-REDD, 2013; UN-REDD, 2011). Generally, there are two categories of countries benefiting from REDD+. The first is called “*countries receiving support to national programs*” to which we have countries like Nigeria, Democratic Republic of Congo inter alia. Here, REDD+ funds the national programs that in turn funds local emissions reduction initiatives. The second category to which Cameroon belongs is called “*other partner countries*” (UN-REDD, 2013). Therefore, getting into the category of “*countries receiving support to national programs*” should be a priority of the government.

However, these strategies are likely to face several challenges along the lines of power structures, socio-economic bulwarks that reinforce the status quo. It has been argued that deforestation in Cameroon is fuelled by the growing population in key land use systems such as agriculture and lumbering which have connections with various governance regimes and will do everything to maintain the status quo (Murdiyarso *et al.*, 2012). To make things worse, an achievement of REDD+ objectives in Cameroon is further weakened by the presence of a weak systems of vertical and horizontal administration, limited involvement of vulnerable indigenes and the fact that the proceeds from the REDD+ program might never get to the vulnerable groups since forest governance is mainly in the hand of the government (Murdiyarso *et al.*, 2012; Pham *et al.*, 2009).

A major policy shift at the national level can take place if economic priorities and power shifts among the actors or stakeholders takes place. Also, tenure security would be an effective way of achieving REDD+ in Cameroon. This is seen as property rights over land, forests, trees and carbon will enhance management. Also, an adequate system of monitoring REDD+ in Cameroon would be to enhance access to basic forest data bases and advanced techniques of monitoring carbon dynamics such as satellite and remote sensing (Brockhaus *et al.*, 2012; Sunderlin *et al.*, 2013).

7.6.1.2. Trade in forest products and fuel wood

In this domain, this study calls for the enforcement of strict laws to restrict the over exploitation of forest products, logging and the extraction of fuel wood. All these could be achieved through a quota system in which specific levels or limits of exploitation are set (Tollefson, 2009). In this way, every exploiter that exceeds their quota of exploitation will be liable to pay penalties for non compliance. Closely linked to this is the enforcement of strict systems of licensing in which quotas and penalties are specified (Nepstad *et al.*, 2009; Gunilla *et al.*, 2013). For those dependent on fuel wood as a source of energy/fuel and income, major shifts to other renewable energy/fuel sources is recommended. Examples are sun, wind, rain, tides, waves, and geothermal; but the finances to invest in these must be available. This is particularly feasible as the country is a tropical nation with a zenith sun radiation position, numerous rivers and an extensive coastline. However, the government will have to make these available and affordable through partnerships with the World Bank and mechanisms such as the clean development mechanisms. The income lost from trade in fuel wood and forest products can be replaced by diversification of livelihoods such as investments in renewable energies, intensive farming, rearing of animals, 'small businesses' through the harnessing of local resources such as medicinal herbs, fruits, beekeeping, and the gathering of mushrooms (Figure 7.5.) (Mwape and Gumbo, 2010; Naughton-Treves and Day, 2012). In other parts of Africa, deforestation has been linked to a lack of sustainable measures of forest exploitation. For example, in east Africa, several decades of development projects have targeted a reduction of dependence on wood fuels and switching to alternative energies (Angelson, 2009; Brockhaus *et al.*, 2012).

7.6.1.3. Cattle Stock

The main problem here is that as the cattle move from place to place they tend to degrade both grasslands and forests. Just like with arable farming, a system of intensive cattle rearing in ranches or clearly specified rangelands is a feasible option.

This measure has been successfully used in Indonesia (Tomich *et al.*, 2001). Such systems of farming will need inputs from the government to enable the people adapt with intensive farming. In this case, medium term loans and training programs on fodder management will be set up to provide the farmers with the capital necessary to establish their intensive farms and to understand the intricacies of fodder management (Nepstad *et al.*, 2009). As in Brazil, farmers who opt to reduce their rangelands could be compensated through a financing mechanism put in place by the government such as under REDD+ and the African Development Bank (Figure 7.5.) (Tollefson, 2009).

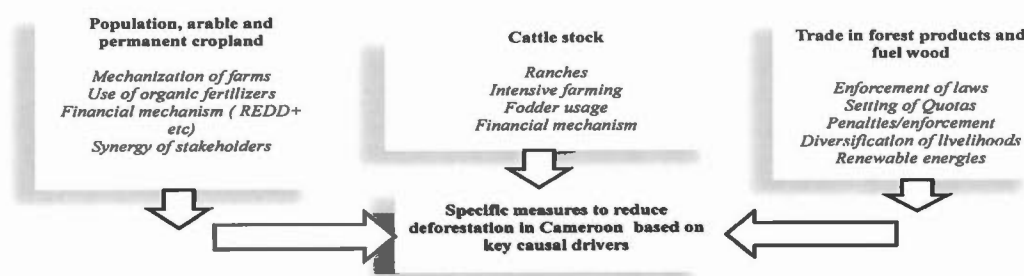


Figure 7.5. Specific measures to combat deforestation in Cameroon based on key drivers.

7.6.1.4. Implications of reduced deforestation scenarios on CO₂ emissions in Cameroon

Here, this study discusses results of the effects of reduced deforestation on CO₂ emissions, GDP and jobs based on four deforestation reduction scenarios (i.e. Business as usual, 25%, 50% and 75% reduction scenarios) from the current annual rate of forest loss in Cameroon. The annual forest area loss in Cameroon between 1990 and 2010 was estimated at 220 Kha per year while the amount of forest carbon lost per hectare is 462 t (FAO, 2010a, b). The CO₂ emission savings associated to these results per scenario are as follows:

Scenario one: $220\,000\text{ ha} * 462 = 101640000\text{t}$

Scenario two: $165000 \text{ ha} * 462 = 76230000\text{t}$

Scenario three: $110000 \text{ ha} * 462 = 50820000\text{t}$

Scenario four: $55000 \text{ ha} * 462 = 25410000\text{t}$

The observations show that when the BAU scenario is maintained, CO₂ emissions are highest and stand at about 101640000t. For this scenario, the contribution of forestry to the GDP is 10% while between 45000 to 70000 jobs are created (Alemagi and Kozak, 2010; Amariei, 2005; CBFP, 2006). In the case of scenario two (i.e. 25% reduction in deforestation), CO₂ emissions fall to about 76230000t. The contribution of forestry to GDP will drop to 7.5% while the number of jobs created by forest related activities will equally drop to between 33750 to 52500. In scenario three (i.e. 50% reduction in deforestation), CO₂ emissions fall to about 50820000t. The contribution of forestry to GDP will drop to 5% while the number of jobs created will also drop to between 22500 and 35000. In the case of scenario four (i.e. 75% reduction in deforestation), CO₂ emissions will reduce to 25410000t while the contribution of forestry to GDP will be 2.5% and forestry will create between 11250 to 17500 jobs (Figure 7.6, Table 7. 2).

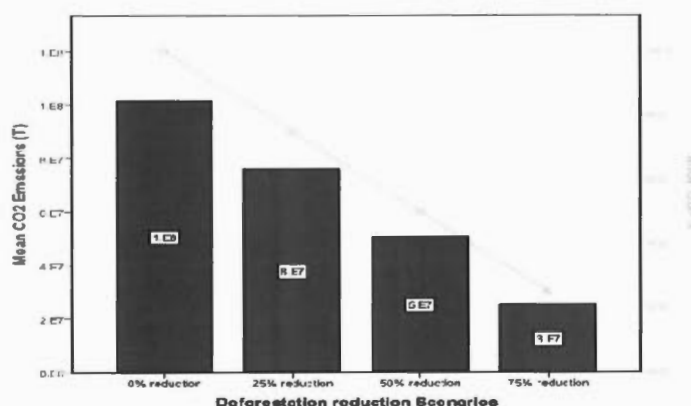


Figure 7.6. The relationship between different deforestation reduction scenarios and GDP.

Table 7.2. Deforestation reduction scenarios and effects on CO₂, GDP and Employment

Scenarios	CO ₂ emissions (t)	GDP %	Employment
Business as Usual	101640000	10	45000-70000
25% reduction	76230000	7.5	33750-52500
50% reduction	50820000	5	22500-35000
75% reduction	25410000	2.5	11250-17500

The overriding trend is that as deforestation reduces, there will be a reduction in CO₂ emissions lost to the atmosphere; however, the economic repercussions are negative as the contribution of forestry to GDP and employment will drop as well. What is crucial here is that the government of Cameroon should get involved in REDD+ or some other financial compensation mechanism such that the economic losses experienced in reducing deforestation and carbon emission could be compensated as is the case of Brazil (Tollefson, 2009). At a regional level, the government of Cameroon could partner with the African Development Bank and other African countries to reinforce its stakeholder involvement in its REDD+ program. This would involve partnering at a transboundary level where countries can exchange ideas on best practices (Gunilla *et al.*, 2013).

7.7. CONCLUSIONS

This study has shown that monitoring population growth and arable production through intensification of production is promising. The general policies that this study postulates are enforcement, legal adherence, specification of tasks and quotas, collaboration, forest licensing and monitoring. More specific policies could be within the REDD+ mechanism as well as diversification of livelihoods, mechanization, use of fertilizers and intensive cattle farming inter alia. Reductions in deforestation will reduce atmospheric CO₂, employment in the forestry sector and the share of forestry's contribution to the GDP.

To cover up for the declines in GDP and employment that will be observed, adherence to subsidizing mechanisms like REDD+ will be a good step forward to replace the losses. This entails projects and cooperation between rich and poor countries in which Cameroon could be compensated for cutting down deforestation as is currently the case in countries like Brazil. Since Cameroon has already been involved in REDD+, the true way forward is getting the local populations involved in the conceptualization and implementation of the plans. This will also entail a global synergy involving other countries with high rates of forest loss in Africa such as the Democratic Republic of Congo *inter alia*. As such, reductions in deforestation will be based on adequate international collaboration on producer and consumer products coming from the forest sector. However, this effort will be worthless if regional/global synergies of nations coming together to curb the unsustainable trade in forest and forest products is not considered. This means that, if Cameroon adheres and other countries persist in the global demand and supply for uncertified or out of quota forests and forest products, then, the net effects will be negative.

Major policy shifts at the national level can take place if economic priorities and power shifts among the actors or stakeholders takes place. Also, tenure security would be an effective way of achieving REDD+ in Cameroon. This is seen as property rights over land, forests, trees and carbon will enhance management. Also, an adequate system of monitoring REDD+ in Cameroon would be to enhance access to basic forest data bases and advanced techniques of monitoring carbon dynamics such as satellite and remote sensing.

However, being that the implementation of REDD+ is still at a trial phase, there is still much uncertainty as to what the future holds. Perhaps therefore an alternate approach is to use a participatory approach to find out from the people in the different forest communities the possible policies that can be helpful. It may also be helpful to verify the bulwarks that can hamper the success of the REDD+ mechanism in Cameroon.

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CHAPTER VIII

GENERAL CONCLUSION AND FUTURE DIRECTION

8.1. SUMMARY OF FINDINGS

In chapter two, this study has been able to use a multiple linear regression model based on time series data to validate the hypothesis that population growth and arable farming are at the core of forest area loss in Cameroon. In chapter three this study has shown that forest area loss leads to increase atmospheric CO₂. In chapter four, the study has also shown that forest area decline is more responsible for cereal yield deficits than rainfall dynamics. It has also been observed in chapter four that as we move from the extreme north region southwards, NDVI increases. In addition, this study used population perceptions to determine that the very low income groups and females are more vulnerable to food and water shortages resulting from forest area loss. This is invariably linked to the fact that the communities are those in which the responsibility of providing household food needs and water is assigned to women and children. Finally, the absence and presence of stakeholder participation are respectively responsible for success and failure in tree planting projects as seen from population perceptions; biophysical factors such as rainfall, soils and geology are less important because if the socio-economic and technical variables are well managed, then success can still be attained. Intensive policy shifts that take into consideration the agents and key drivers of deforestation as well as financial mechanisms such as REDD+ should be taken into consideration.

8.2. LIMITATIONS OF THIS STUDY AND WAY FROWARD

This study has identified the causes, effects and policies that can reduce forest area loss in Cameroon. This study assumes a fixed annual rate of loss in forest area of 220

Kha, the data used do not include variables such as fires, soil fertility, acid rains and insects. Income levels are used as the main indicators of poverty levels.

8.2.1 Rate of loss in forest area

The observed trends in forest area loss are based on an assumption of 220 Kha/year of forest loss each year during the decade 1990-2000 in Cameroon (FAO, 1990; FAO, 2010). If we argue that population growth changes over time, then, the population's needs for forest will equally increase progressively. As a result of this, some uncertainty is factored into the model. However, we have to depend on the current estimate as the 220 Kha/year was initially adopted by the FAO as the loss per year during the decade 1990-2000. This study has suggested various policies that can help in reducing deforestation in Cameroon. However, as can be observed, this will imply an increase in atmospheric CO₂, reduced employment and GDP. A possible trade off here could be the adoption of carbon trading and carbon credit schemes. This will mean setting fixed quotas for carbon emissions in terms of number of hectares of trees cut such that emissions can be traceable and quantifiable. To make this more feasible and attractive, those who exceed their quotas will be expected to buy excess credits from those who did not exhaust theirs. This mechanism comes very close to the objectives of REDD+ (Bhardwaj, 2013).

8.2.2. Other disturbances

Furthermore, this study is limited by the absence of data on variables such as fires, insects, acid rains. Insects for example are crucial in forest ecosystems dynamics (Nair, 2007; Kurz *et al.*, 2008). Fire for example is known to affect tree species density, tree species diversity, forest organic matter depth, rates of decomposition, structure and age of forests (Harden *et al.*, 2000; Bond-Lamberty *et al.*, 2007). Unfortunately, this study does not use any of these variables for reasons of data availability in Africa. It is therefore suggested that inventories of such data bases be developed as testing forest area loss against these shall help improve prediction. Also, in setting up the multiple linear regression models, it's observed that some of the

independent variables are affected by collinearity as they tend to be dependent on each other. This has been fixed by progressively deleting concerned variables to optimize and re-running the models.

8.2.3. Rainfall and re-greening

The basis of concluding that rainfall and greening in the Sahel in general and in Cameroon in particular are rising positively is based on NDVI studies (Anyamba and Tucker, 2005; Seaquist *et al.*, 2006; Olsson and Mryka, 2008; Olsson *et al.*, 2005; Herrmann *et al.*, 2005; Epule *et al.*, 2012). The NDVI should be treated with caution because in the Sahel, NDVI tracks mainly interannual variability in herbaceous vegetation. The NDVI is an index of the portion of photosynthetically active radiation absorbed by plants and this is proportionate to green leaf area. In the Sahel, the green leaf area of herbaceous plants is composed mainly of annual grasses and it highly exceeds the green leaf area of trees and shrubs which are responsible for allocating more biomass; unfortunately, the NDVI is unable to detect the latter (Gonzalez *et al.*, 2012). Furthermore, NDVI coverage in the Sahel began in 1982. With the droughts of 1982-1984 and a slight increase of rainfall in the 1990s, a short term increase in the NDVI was observed, however, the NDVI can only show herbaceous vegetation increase and this is available only from 1982 (Anyamba and Tucker, 2005; Seaquist *et al.*, 2006). Therefore, the trends before 1982 are not covered by NDVI. To aptly respond to this situation, this study recommends that more local grass root based studies should be carried out to confirm the exact trends in different spatial locations because the cases of enhanced greening may be due to improved water management in more affluent communities (Giannini *et al.*, 2008).

The primary cause of most of the Sahelian droughts is more or less linked to human oriented land use patterns such as deforestation. Other causes include dust feedbacks, vegetation degradation and sea surface temperatures. The human related factors are more important because they impact all the other variables. The picture presented here is also similar when it comes to the main vector behind forest area loss and

dynamics in Cameroon. We can therefore argue that, with a continuous surge in deforestation, the environment will remain fragile, carbon emissions will rise, the current rise in rainfall will not be available to alter these woes and recurrent droughts and associated food shortages will be observed (Epule *et al.*, 2014).

8.2.4. Vulnerability

Furthermore, this study has looked at vulnerability from an income and gender perspective. However, it is being suggested that other indicators of vulnerability such as age, education and location etc be analyzed. The use of income levels as indicator for poverty levels is good but could trigger in some uncertainties in this study. This is so because poverty levels can be defined beyond income levels. Other possible indicators of poverty are availability of food, sanitation, health, shelter, education, information inter alia (Gordon, 2005). This study therefore suggests that other studies of vulnerability should widen the scope of the meaning to encompass many other variables.

8.3. CONCLUSION

Due to the rapid rate of loss of forest in Cameroon, several attempts have been made by the government through policies and the setting up of institutions to reduce deforestation. However, economic pressures such as the desire to keep the GDP and employment rising have all helped in making the remedial efforts worthless. To make things worse, the remedial measures have been based on generalizations of what exactly the causes of forest area loss are. As such, this thesis enhances our understanding of the causes and effects of forest area loss in Cameroon. It also shows the interactions between causal variables, the extent of population vulnerability along gender and income lines, sets out options for tree planting and proposes policies that can help reduce forest area loss in Cameroon within a win-win context. It draws a clear line on the relative contributions of deforestation and rainfall in accounting for the state of cereal production in Cameroon. By quantifying the causes of forest area

loss and reasons for success and failure in reforestation this study creates room for the possible policies that can be put in place to subvert forest area loss.

Reforestation has long and short term effects on the state of the soil. In the short term, it can reconsolidate the soils stability by reducing erosion. In the long term, the inputs from the leaves of plants and increase soil aeration can enhance soil organic carbon (SOC) and soil organic nitrogen (SON) and consequently agriculture and forests. A study carried out in Western Fujian Province of China has been used to show that increase reforestation increased above ground biomass. However, the accumulation of SOC and SON varied with the age of the projects. This is seen as a reforestation project that had existed for ten years had far less SOC and SON when compared to that which had existed for about 18-30 years (Dan *et al.*, 2013)

8.4. REFERENCES

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APPENDIX A

THE CAUSES, EFFECTS AND CHALLENGES OF THE SAHELIAN DROUGHTS: A CRITICAL REVIEW

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A.1. RÉSUMÉ

Cette étude cherche à synthétiser les différentes méthodes de modélisation de la sécheresse, analyse les causes de la sécheresse, les effets de la sécheresses sahéliennes et les défis et la manière en avant. Basé sur la synthèse conduite, cette étude a montré que plusieurs méthodes quantitatives de simulation de sécheresse existent. Les quatre causes principales des sécheresses sahéliennes, les facteurs causés par l'homme sont vus comme dominants. D'autre part, les effets des sécheresses sur les forêts et des systèmes de rendement agricole sont regardés en grande partie en termes de augmentation de la mortalité d'arbres, réduction de diversité d'espèces/densité, rétraction de forêt, réduction de la séquestration de CO₂ et réduction des rendements agricoles et dessication des cultures. Cette étude prouve également que depuis les années 1990 il y a eu une augmentation de la précipitation dans le secteur d'étude. La synthèse montre également que la l'augmentation de CO₂ augmentera les arbre. Les défis principaux en surmontant les effets des sécheresses sont VIH/SIDA, le paludisme, instabilité politique, disponibilité de données et manque d'observations appropriées.

A.2. ABSTRACT

This paper is a critical synthesis of the causes, effects and challenges of the Sahelian droughts. The results show that the four main causes of the Sahelian droughts are: sea surface temperature changes, vegetation and land degradation, dust feedbacks and human induced climate change. However, human induced climate change is seen as the major drought determining factor because it controls sea surface temperatures, dust feedbacks and vegetation degradation. Increase rainfall and greening have been observed in the Sahel since the 1990s; yet, food yields remain low while tree mortality rates are high. The implication of this is that the rainfall is not available for agriculture since various human induced climate change processes such as deforestation and the expansions of arable farms do not make the moisture available for agriculture. The increase in tree mortality has also been found to increase atmospheric CO₂ in the study area. However, this study hypothesizes that the increase CO₂ might be responsible for the increase in greening and rainfall observed. This can be explained by an increased aerial fertilization effect of CO₂ that triggers plant productivity and water management efficiency through reduced transpiration. Also, the increase greening can be attributed to rural-urban migration which reduces the pressure of the population on the land. The remittances from migrant urban workers may make farming more sustainable in the rural areas, thus enhancing greening. The principal challenges in overcoming the effects of the droughts are HIV/AIDS and Malaria, political instability, data availability, proliferation of extensive non mechanized farms and lack of adequate observations.

Keywords: droughts, human induced climate change, tree mortality, CO₂ emissions, food yields, HIV/AIDS, national security.

A.3. INTRODUCTION

The Sahel is a semiarid strip of land that is transitionally located between the tropical rainforest in the south and the arid north of Africa (figure A.1) (Olsson and Mryka, 2008). It covers an area of about $3,053 \times 10^3 \text{ km}^2$ and has about 60 million inhabitants. The rainfall in the region is highly variable. At the 17° isohyet (northern boundary of the Sahel) less than 200 mm of rainfall are recorded annually while further south at the 15° isohyet (southern boundary of the Sahel), about 450-500 mm of rainfall are recorded annually (Wang *et al.*, 2005; Zeng, 2003). During the months of April to July the temperatures are about 32 to 35° C throughout the Sahel (Nicholson 1995). The most prominent of the droughts that have effected this region are those that began at the end of the 1960s and ended in the mid 1980s (Anyamba and Tucker, 2005).

Climate change plays an important role in African development and cannot be left out of the debates on droughts and ecosystem responses in Africa (Giannini *et al.*, 2008; Reynolds *et al.*, 2007; Giannini *et al.*, 2003; Lu and Delworth, 2005). The evidence that global climate has repercussions in the study site is based on remotely sensed observations of vegetation cover dynamics, models of land cover responses to changes in precipitation and land use models of African rainfall response to global sea surface temperature changes (Giannini *et al.*, 2008; Anyamba and Eastman, 1996; Prince *et al.*, 1998; Nicholson *et al.*, 1998; Eklundh and Olsson, 2003; Herrmann *et al.*, 2005).

On the other hand, the view that the Sahel is becoming increasingly green and wet should not only be based on remotely sensed data but be correlated by results of local surveys of population perceptions before a conclusion can be made because in less wealthy communities, there are reports of no such climatic adjustments as food yields remain persistently low (Giannini *et al.*, 2008; Olsson and Mryka, 2008; Herrmann *et*

al., 2005; L'Hôte *et al.*, 2002). In wealthier communities, the ability to invest in water management has favored crop production (Giannini *et al.*, 2008; Reij *et al.*, 2005). It can be argued that the return of wetter and greener conditions in the Sahel is a product of land management efforts and not a return to pre-drought conditions of the years before the 1960's (Giannini *et al.*, 2008). As such, this study aims at synthesizing the primary literature to uncover the key causes, effects and challenges imposed by the Sahelian droughts. To the best of our knowledge, this is the first comprehensive synthesis of the causes, effects and challenges of the Sahelian droughts in one study. Prior to this study, much of the information was found in diverse publications that dealt with different aspects of the droughts. The main gap that this study therefore fills is being able to synthesize the primary literature while vividly reviewing the causes, effects and challenges of the droughts. In another section on supplementary online information, the parameters, methods of drought quantification and simulation are also reviewed.

A.4. THE CAUSES OF SAHELIAN DROUGHTS

The debates on the causes of the Sahelian droughts have been very intense and controversial (Lamb, 1978; Hulme, 2001). In the midst of a lot of research, a consensus on the mechanisms responsible has not been achieved (Thiaw and Mo, 2005; Biasutti and Giannuni, 2006).

A.4.1. Sea Surface Temperatures (SST)

The West African Monsoon (WAM) is the main source of rainfall in the Sahel (Weldeab *et al.*, 2007; Giannini *et al.*, 2005; Hulme, 2001; Zeng *et al.*, 1999). Several studies have modeled the relationship between the pattern of SST and Sahelian rainfall using statistically based climatological analysis that show that with the onset of Sahelian droughts in the late 1960s, a particular configuration of global SST characterized by warm anomalies in the southern hemisphere and cool anomalies in the Northern hemisphere Oceans (Gleckler *et al.*, 2008). Based on data spanning the

period 1930-2000, it has been argued that the warming in the Atlantic Ocean has been weakening the moisture laden WAM, causing a southward shift in the Inter-tropical Convergence Zone (ITCZ). This decreases moisture input and reinforcing the weakening of the WAM, creating drier conditions with less vegetation and higher albedo (figure A.1) (Zeng, 2003; Bader and Latif, 2003; Zhang and Delworth, 2006).

The trends in SST patterns above are plausible in explaining the droughts of the Sahel. However; they are not able to explain the situation for the individual years (Hagos and Cook, 2008). The repercussions of the El Nino (warm waters in the Pacific Ocean) in the Sahel are that they also result in a weakened WAM flow due to the northward shift of the mean sea level pressure (MSLP) along the coast of west Africa and hence create dry conditions over the Sahel (Camberlin *et al.*, 2001; Thiaw and Bells, 2005; Chelliah and Bell, 2004; Kang *et al.*, 2008; Hoerling *et al.*, 2005; Wolff *et al.*, 2011; Held *et al.*, 2005; Janicot *et al.*, 2010; Hurrell *et al.*, 2003; Shanahan *et al.*, 2009).

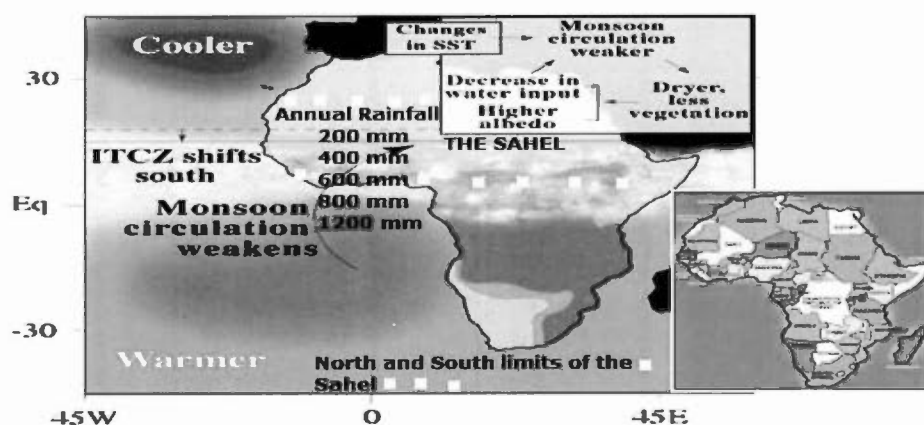


Figure A.1. Recent Sahel droughts caused by global sea surface temperature (SST) which reduced the strength of the West African Monsoon.

Source: Modified from Zeng, (2003).

A.4.2 Effects of Vegetation and land degradation

One of the earliest view points on the causes of the Sahelian droughts was based on the Charney hypothesis (Charney *et al.*, 1977; Fuller and Ottke, 2002). This hypothesis holds that the recent droughts in the Sahel are caused by a declining vegetation cover (Olsson and Mryka, 2008). According to this model, declines in vegetation cover caused by overgrazing, the conversion of woodlands into agricultural lands and wars has cause an increase in the reflectivity or albedo of the landscape (Zeng, 2003; Clover, 2010; Fuller and Ottke, 2002). This results in a reduction in the heating of the earth as less sunlight is absorbed and reduced moisture to the atmosphere that is responsible for the production of convection responsible for the rainfall (Zeng, 2003).

There is an inverse relationship between latitude or mean surface albedo (coefficient of reflectance) and mean annual rainfall and a direct relationship between latitude and albedo in the Sahel (figure A.2). At 15° N (the south boundary of the Sahel) the surface albedo was 0.30 while mean rainfall for 1983-1988 was about 450 mm. However, at 17° N (the north boundary of the Sahel) the surface albedo is about 0.43 and the mean rainfall for the same period is about 200 mm. This is explained by the northward reduction in vegetation that reduces evapotranspiration (figure A.2) (Nicholson *et al.*, 1998; Wang *et al.*, 2005). The question is, have such large anthropogenic offsets really taken place? A recent evaluation of population dynamics and the history of land use change in the Sahel holds that over the last 35 to 40 years there is evidence of just modest land use changes that is not nearly enough to explain the observed droughts (Zeng, 2003). On the other hand, the idea that the Sahel witnessed a lot of land degradation and deforestation was supported by (Lamprey, 1975) who asserted that the Sahara had advanced by 90-100 km in the North of Sudan between 1958 and 1975.

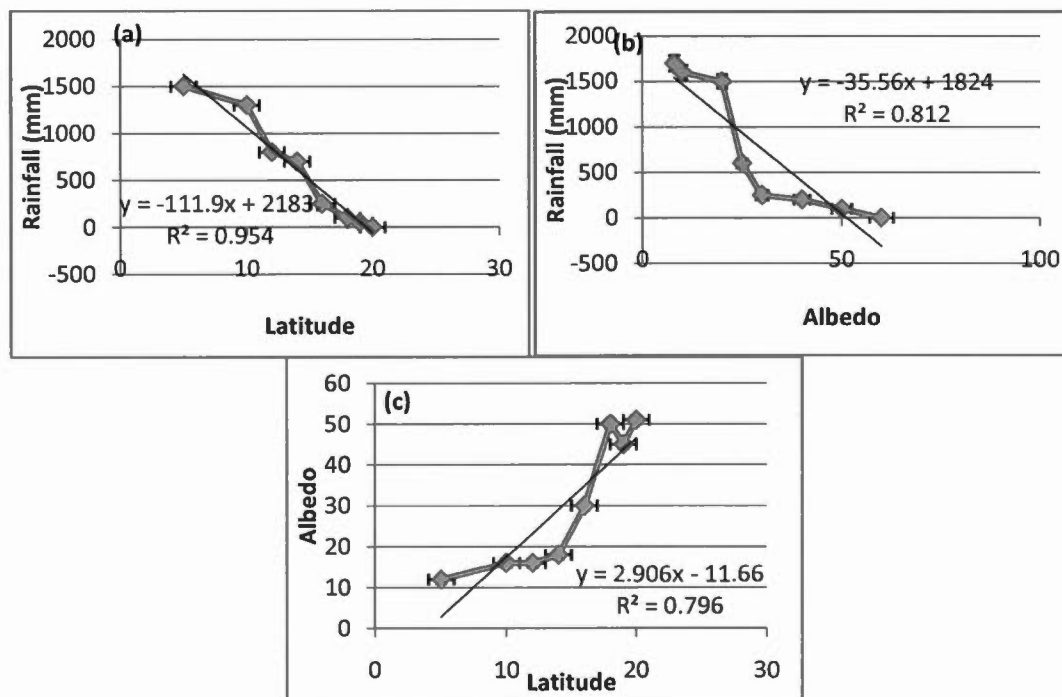


Figure A.2. The relationship between (a) latitude and rainfall, (b) surface albedo and rainfall, (c) latitude and surface albedo.

Source: Inspired from Nicholson *et al.*, (1998).

A.4.3 Dust feedbacks

The Sahara desert is the world's largest source of airborne dust (N'Tchayi Mbourou *et al.*, 1997). About one billion tones of mineral dust are transported from the Sahel-Sahara. Dust aerosols from the Sahara desert are said to contribute approximately half of the total atmospheric aerosols which are estimated at 1500 Tg per year (Ramanathan *et al.*, 2001).

The accumulation of Sahelian dust in the atmosphere further reduces rainfall by increasing the number of cloud condensation nuclei in warm clouds and thereby affecting the surface radiation budget's instability. This is because the dust particles suppress rainfall by promoting the formation of small cloud droplets which do not reach the size of rain drops and possibly increase evaporation of clouds due to

increase absorption of solar radiation (Lohmann and Feichter, 2005). It has been argued further that, dust aerosols can contribute to surface heating by reflecting incoming solar radiation (Li *et al.*, 1996); this enhances warming in the troposphere and thereby increasing atmospheric stability, reducing convection and reducing rainfall (Lintner and Chiang, 2006). Atmospheric dust can also absorb long wave outgoing radiation thus providing a green house effect (figure A.3). (Hui *et al.*, 2008; Kaufman, 2002). Reduced rainfall is said to result in drier soils, less vegetation and increase potential for the wind to blow off more dust minerals into the atmosphere (Rosenfeld *et al.*, 2001; Lu and Delworth, 2005). As observed on satellite images of dust outbreaks from the west coast of Africa, the dominant period of transport of Sahelian dust is usually in summer (Prospero and Lamb, 2003).

A troubling issue is the fact that their impact on the hydrological cycle in some Sahara desert margins such as the West African Sahel has not been quantified. Most studies have focused on the physical and microphysical mechanisms of rainfall reduction (Adhikari *et al.*, 2005; Neelin and Su, 2005). A few others have analyzed the correlation between aerosols and cloud cover over several rainy seasons and found that in West and East Africa, dust accumulation helped in reducing rainfall (Mahowald and Kiehl, 2003; Hiu *et al.*, 2008).

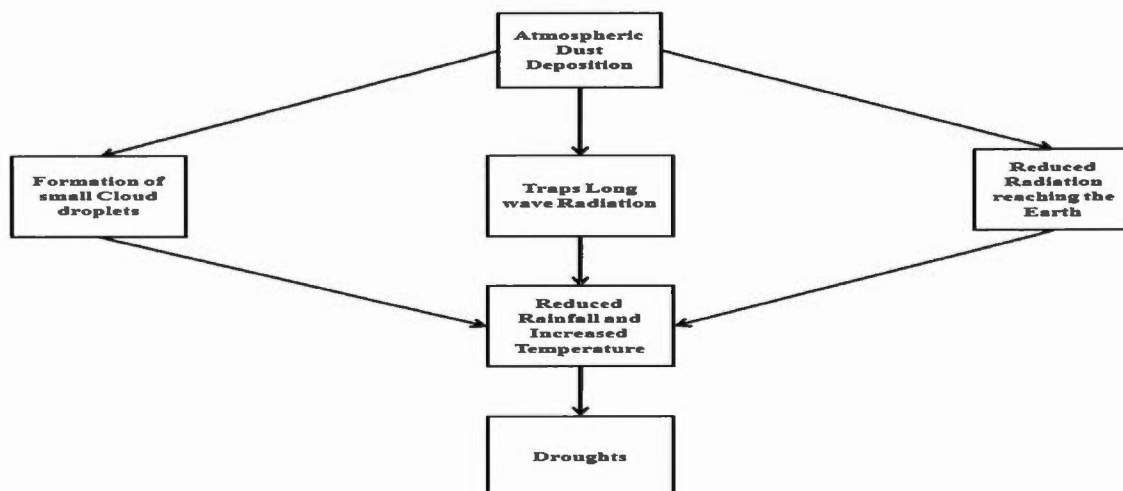


Figure A.3. Interactions between dust feedbacks and droughts.

Source: Inspired from Prospero and Lamb, 1982; Prospero and Needs, (1977); N'Tchayi Mbourou *et al.*, (1997).

A.4.4 Human Induced Climate Change

Human induced climate change (CC) is mainly concerned with deforestation and land degradation through various unsustainable methods of cultivation and the spewing of GHGs such as carbon dioxide (CO₂) (figure A.4), (Tippet, 2006; Vecchi and Soden, 2007; Epule *et al.*, 2011). Between 2000 and 2010, it was reported that Africa had a net loss of forest of about 3.4 million hectares/year while the global rate was 13 million hectares/year during the same period (FAO, 2010).

In terms of GHG emissions, the Sahel had a rate of 0.9 % per capita in 1980 and 0.8% per capita in 2007 while Latin America and Asia had rates of 0.4% and 0.1% per capita in 2007 (World Resource Institute (WRI), 2011). This increase GHG emission was greatly associated to a 28% increase in population between 1960 and 2006 at a rate of about 2.2 percent and a rate of deforestation of about 0.5 to 0.7% for the Sahel (Roncoli *et al.*, 2002; Li, 1996). On a prognostic basis, it has also been

argued that human induced global warming will be associated to a wetter regime in the Sahel and the southern Sahara. These finding is based on a simulation of 150 years that includes an ocean-atmosphere-sea-ice model driven by fluctuations in CO₂. The results show that an enhanced monsoon is responsible for increase precipitation over West Africa towards the end of the 21st century (Maynard *et al.*, 2002; Rotstayn and Lohmann, 2002; Knutson *et al.*, 2006).

Generally, it has been argued that global SST changes are more responsible for the droughts in the Sahel. Such evidence is based on a comprehensive modeling study by Giannini *et al.*, (2003). The authors used the results from a state of the art general circulation model (GCM) and principal component analysis (PCA) to argue that when SST observed between 1930 and 2000 are set in the model; the model reproduces much of the variability in the observed Sahelian rainfall. The importance of SST as a factor that causes droughts goes beyond the African continent. In a study on Canadian boreal forests, Peng *et al.*, (2011) show that SST have been partly responsible for the droughts that are responsible for higher levels of tree mortality in the western part of Canada.

However, this current synthesis is of the view that human induced CC through deforestation triggered by unsustainable methods of cattle rearing and farming are more significant. This is because, even when SST, albedo and dust feedbacks are considered, human induced environmental and climate change activities have a role to play. Therefore, this synthesis suggests that a better understanding of the causes of droughts in the Sahel can be achieved if researchers go beyond disciplinary boundaries and get involved in systemic or synergetic studies by bringing all the drivers on board.

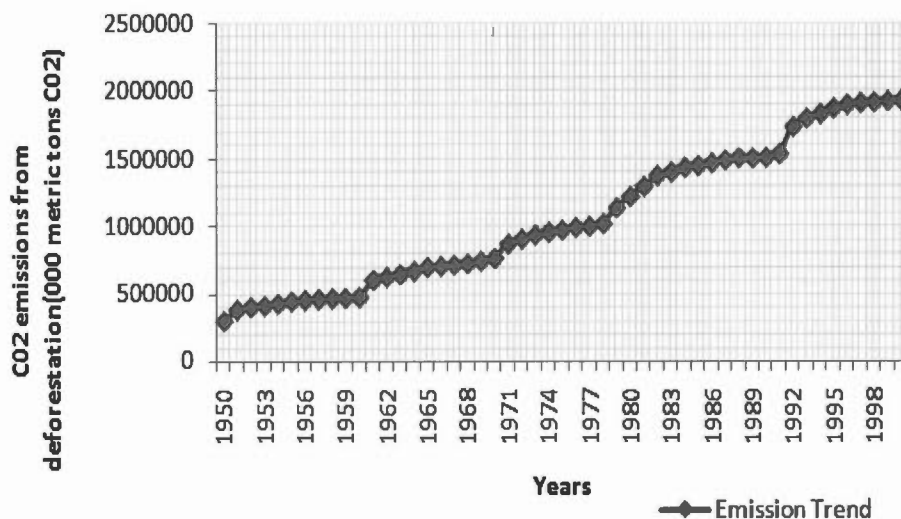


Figure A.4. CO₂ emissions from deforestation in sub-Saharan Africa, 1950-2000.
Source: Inspired from data obtained from (<http://www.wri.org>) World Resource Institute, (2011).

A.5. THE EFFECTS OF DROUGHTS ON ECOSYSTEM SERVICES

The observed droughts that have affected the Sahel have produced effects on trees and crop yields. This section of this paper reviews the possible effects of the Sahelian droughts on forests and food systems (FAO, 2006). Examining the effects of these droughts on food and forest ecosystems is important for the following reasons: 1. Agriculture employs close to 80% of the population in most African countries and 2. Forest mortality does not only create problems of CO₂ sequestration but also affect soil compactness, hampers agriculture, reduce environmental aesthetics, reduce the recreation and spiritual benefits of forests *inter alia* (Gonzalez *et al.*, 2012; Epule *et al.*, 2012a). For a synthesis of the key effects of droughts in the Sahel, see table S2 under supplementary information.

A.5.1 The Effects of Droughts on Forests in the Sahel

Towards the end of the 20th century, rainfall in the study area declined by approximately 20-40% and average temperatures increased by 1.3°C (Maranz, 2009).

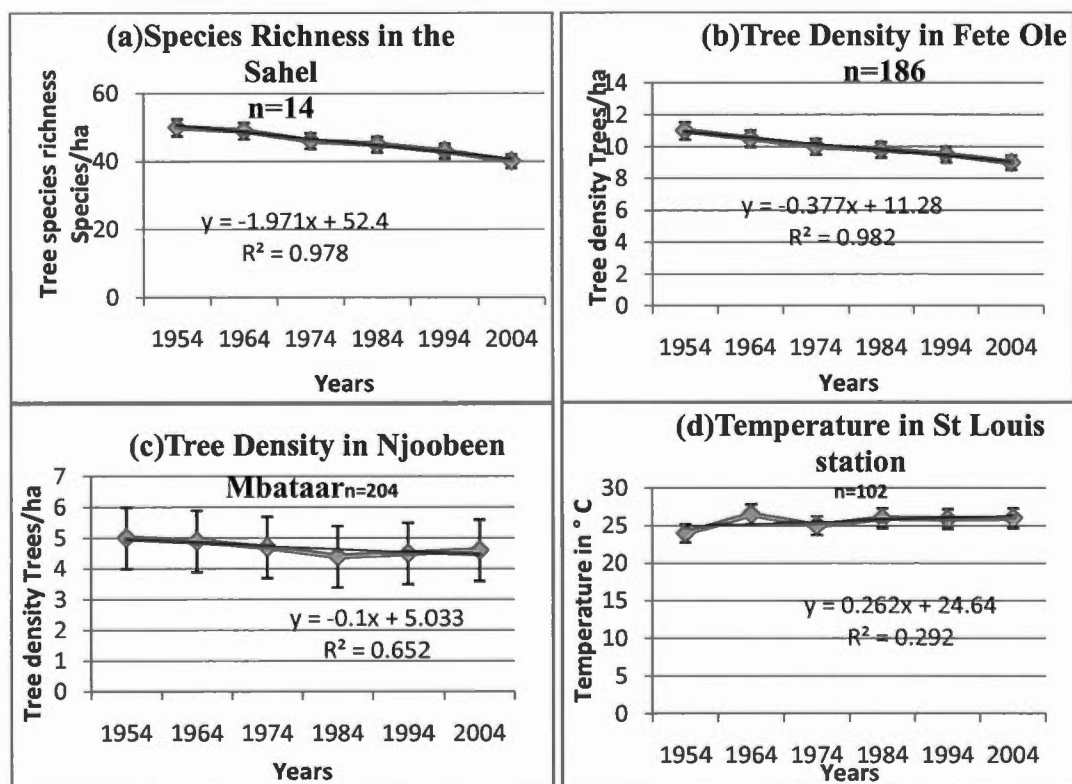
This has been described as the most negative rainfall trend in the world in contemporary times (Nicholson, 2001).

In the last half of the 20th century, the persistence of droughts had been consistent with observed declines in tree density and tree species richness across the study area. A decrease in species richness for most of the study sites in Mauritania, Chad, Mali, Burkina Faso, Niger and Senegal was obtained between 1960 and 2000 (Gonzalez *et al.*, 2012). A study on tree species richness for the Western Sahel in Senegal reports that between 1945 and 2002, the average species richness of an area 4 km² declined from 64±2 to 43±2 species (figure 5.A). In terms of different species, the study holds that the species richness for the Guinea trees and shrubs (mesic species) fell by 54±9%, the Sudan species richness fell by 29±4%, Xeric species, Sahel species fell by 14±4% (Gonzalez, 2001).

With the use of aerial photos and Ikonos images, declines in tree density caused by droughts have been observed in Senegal (figure A.5.a, b, c, d, e). A 29% decrease in tree density between 1972 and 1976 was observed while between 1954 and 2002, a 20% decrease was observed (Gonzalez *et al.*, 2012; Wezel and Lykke, 2006). Decrease in tree density per hectare was recorded at stations in Senegal such as in Njóobéen Mbataar and Fété Olé stations between 1954 and 2002. At both stations, tree density fell by one fifth between 1954 and 2002; tree mortality ranged from 0.11 ± 0.01 at Wolum per decade to 0.33 ± 0.04 per decade at Njóobéen Mbataar (figure A.5c) (Gonzalez *et al.* 2012; Vincke *et al.* 2010). Furthermore, forest retractions in the Guinea and Sudan vegetation zones of Senegal are said to have tilted South-westward by 25 to 30 km with an average rate of 500-600 m/year between 1945 and 1993. These historic shifts took place through high mortality in mesic species leaving drought-resistant species to be the remaining tree cover (Gonzalez, 2001).

Similarly, increased tree mortality that is linked to droughts has been reported in the moist forests of Uganda where the death of mesic species of trees has been observed (Allan *et al.*, 2009; Lwanga, 2003). In a related study, Maranz, (2009) also discussed

the view that rainfall declines of about 100 mm between the period 1930 and 1965 and 1966-2000 in the Sahel was responsible for the disappearance of several trees in the study area. In Burkina Faso, Mali and Sudan, arid trees have expanded due to reforestation by local farmers (Gonzalez *et al.*, 2012; Wezel and Lykke 2006; Hiernaux *et al.*, 2009). In parts of Senegal and Mauritania, human agricultural expansion and livestock grazing have been reported responsible for declines in tree density and not climate (Niang *et al.*, 2008; Wezel and Lykke, 2006). Whatever the case, this may be true locally when it comes to forests near urban areas and areas which serve as routes for the transportation of livestock and migration; for most tree species, a very close correlation to rainfall shifts has been established (Maranz, 2009).



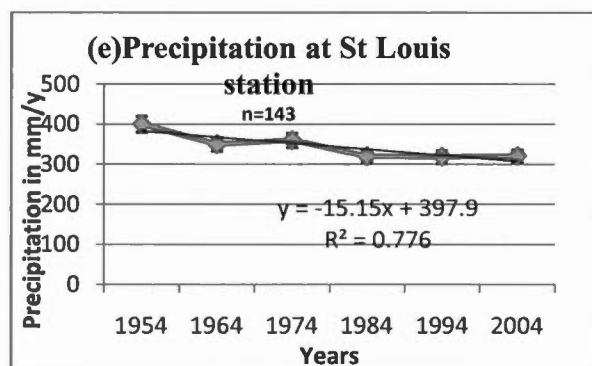


Figure A.5. Variations in tree species richness for the Sahel (a), tree density (b, c), temperature (d) and precipitation (e) for stations in the Sahel

Source: Inspired from Gonzalez *et al.*, (2012).

However, based on observations of increase rainfall in the Sahel from the 1990s, the trends in vegetation seem to be changing the debate. Using Normalized Difference Vegetation Index (NDVI), several recent studies have proven that both rainfall and vegetation have increase in the Sahel since the 1990s (Anyamba and Tucker, 2005; Seaquist *et al.*, 2006; Olsson and Mryka, 2008; Olsson *et al.*, 2005). It is now evident that rainfall and vegetation in the Sahel have increased and have bivariate correlations of 85-90% for the Sahel as seen on figure A.6a. If downscaling is applied to verify the case of Cameroon, it is observed that the correlation between rainfall and tree growth is about 85% for the Sahel of Cameroon (figure A.6b) (Herrmann *et al.*, 2005; Epule *et al.*, 2012a). Giannini *et al.*, (2008) argue that the recovery is not as a result of a recovery in rainfall but due to better land management in some affluent communities. Local studies on population perceptions of these changes are suggested to verify actually what obtains in the ground (Giannini *et al.*, 2008).

The loss of trees in the Sahel has led to increase atmospheric carbon dioxide (CO₂). Even though uncertainties exist on the future of droughts in the study area, most climate projections show that most areas around the mid latitudes in Africa, Australia

and Latin America will continue to be at the risk of droughts due to the fragility of their ecosystems (Molen *et al.*, 2011). Such droughts are likely going to impact atmospheric CO₂ (Knorr *et al.*, 2007). Droughts are known to affect the rate of CO₂ uptake by plants by affecting gross primary productivity (GPP), total ecosystem respiration (TER) (Molen *et al.*, 2011; Meir *et al.*, 2008). CO₂ flux measurements collected in a global network have shown that a majority of sites witnessed increase CO₂ accumulation and reduced GPP and TER due to droughts (Baldocchi, 2008; Schwalm *et al.*, 2010).

A recent study in Senegal shows that the proportion of carbon (C) residing in biomass decreased with time from 55% in 1965 to 38% in 2000. The study holds further that human land use disturbances only accounted for 22% of biomass C loss in 1993, suggesting the dominant role of the long-term Sahelian extended droughts in the region (Woomer *et al.*, 2004).

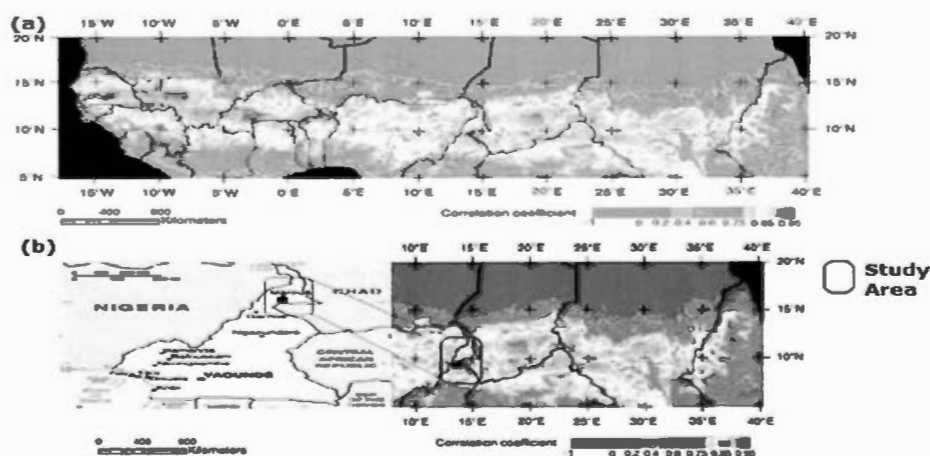


Figure A.6. (a) Correlation between rainfall and vegetation in most of the Sahel in general and the (b) Sahel of Cameroon in particular.

Source: Modified from Herrmann *et al.*, (2005); Epule *et al.*, (2012a).

Generally, the reasons for the observations of increase greening in the Sahel have simply remained speculative or more commonly attributed to rising rainfall and land management in more affluent communities (Herrmann *et al.*, 2005; Runnstrom,

2003). However, while this current synthesis agrees with the role of rainfall and soil/water management as possible reasons for the observed greening, it can be argued that rising CO₂ content above the Sahelian atmosphere has an aerial fertilization repercussion as it triggers plant productivity and causes water management efficiency through reduced transpiration. Therefore, this study suggest that as the CO₂ continues to rise over the Sahel, we should expect further increases in greening; a view supported by (Prince *et al.*, 1998). Also, the increase in greening could be explained by a surge in rural-urban migration which reduced pressure from the agricultural population on land and the remittances from the migrant urban workers to their rural families have increased farm inputs and made farming more sustainable.

A.5.2 The Effects of Droughts on food yields in the Sahel

Per capita food production in the Sahel has declined in the past three decades due to droughts. The food self sufficiency ratios have also dropped from 98% in the 1960s to about 86% in the mid 1980s. On average, every African had 12% less grown food in the 1980s when the droughts were at a zenith than 30 years earlier (Nyariki and Wiggins, 1997).

A huge number of people in developing countries suffer from hunger. More than 850 million people suffer from food shortages globally. About 700 million are from the developing countries while 100 million are from the African continent. Of the 60 million people living in the Sahel, 30 million are facing a food crisis (Nyariki and Wiggins, 1997; Clover, 2010). It was estimated that by the year 2000, the population in the Sahel of SSA would grow by more than 3% per year while food production would grow at 2% per year leaving a majority of the people with insufficient food (Nyariki and Wiggins, 1997). At the forecasted trends, the study area will experience food shortages of close to 250 million tons by the year 2020 (Nyariki and Wiggins, 1997). It is argued that climate variability and extreme weather events such as droughts have for a long time recurrently stood as major factors affecting agricultural

productivity and hence food security (Haile, 2005). During the 1982 droughts in the Sahel, severe food shortages were recorded in over 27 Sahelian countries with notable famines in Chad, Ethiopia, Sudan and Angola (Dilley *et al.*, 2005). However, Glantz, (1994) and Lamb, (1982) argued that things were made worse due to internal wars.

As a result the resurgence of droughts between 1975 and 1985, per capita food production declined by 25% in West Africa. During the onset of the 1984 droughts in Sudan, global attention was on Sudan due to reports of famine in areas like Darfur province, Kordofan province and the Eastern Sudan and Red Sea province (Olsson, 1993). The resultant food shortages affected close to 20-25 million people in Sudan with a 3%/month death rate and Millet and Sorghum yields dropped to about 20% of the normal. The observed or actual yields were below the predicted yields throughout the period 1975-1985 (figure A.7) (Olsson, 1993; Olsson, 1986).

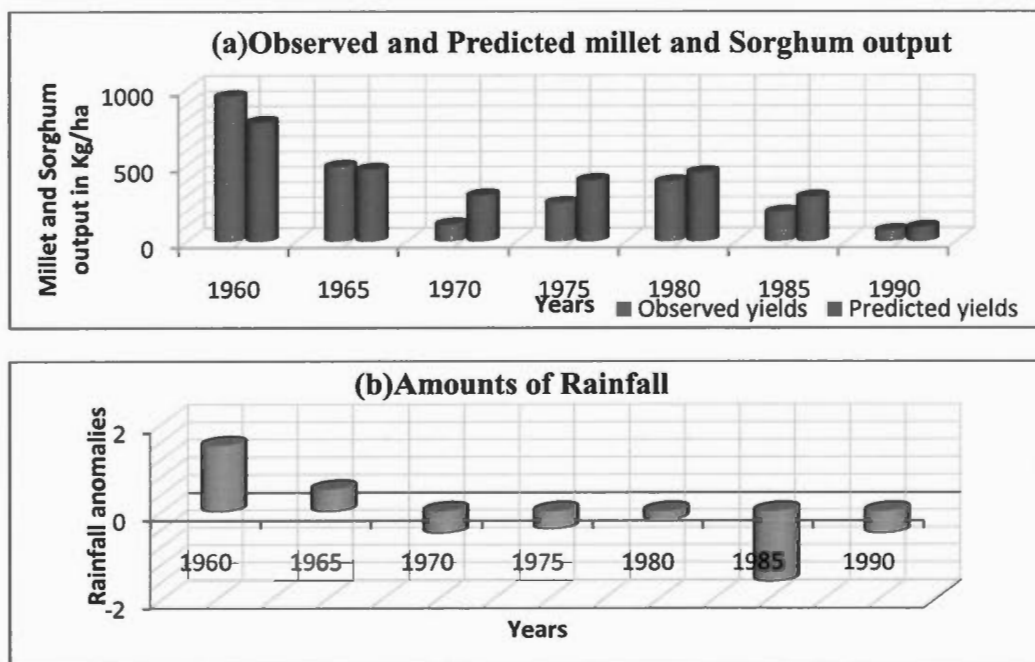
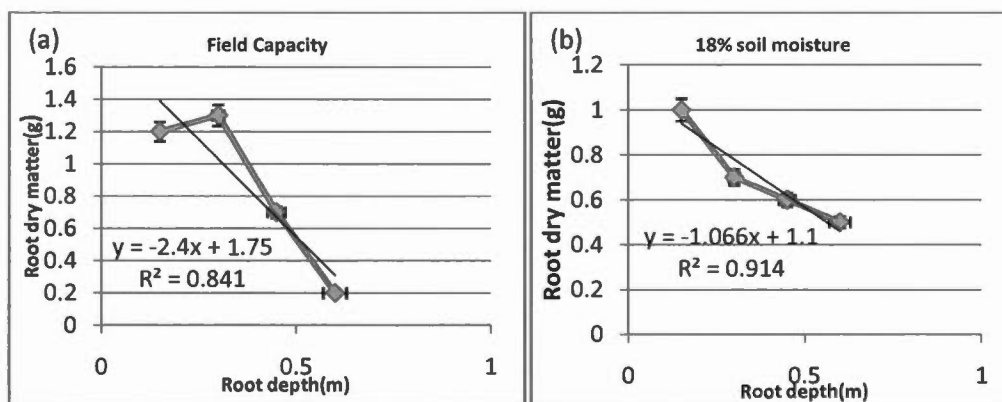


Figure A.7. (a) Variations in observed and predicted millet output in the Kordofan province of Sudan. **(b)** Rainfall anomalies.

Source: Inspired from Olsson, (1993).

In Kenya, Makueni is an agro-ecological zone that is suitable for the growing of millet, maize, cowpeas, pigeon peas, beans and rearing of livestock. About 72% of the households in this community are engaged in farming and livestock rearing (Dinku *et al.*, 2007). In 1999/2000, 91% of the households experienced food shortages for 3 months in 1999 and 5 months in 2000 due mainly to droughts. The resultant food shortages during the 1999/2000 droughts were reflected in a 31% recourse of households to receive food relief; 6% participated in food for work (FFW) activities, 17% received relief food and participated in FFW (Ifejika Speranza, 2006). With the aid of rainfall and crop yield data from 1971-2007, researchers found that Upper West and Upper East of Ghana had higher sensitivities to droughts as crop failures were rampant (Simelton *et al.*, 2009; Antwi-Agyei *et al.*, 2012). In Mbe, Ivory Coast, laboratory experiments that simulate drought conditions show that under water stress the plants reacted through reductions in height, leaf area, biomass production, tiller abortion, changes in root dry matter, rooting depth and a delay in reproductive development (Asch *et al.*, 2005). With progressive droughts, there is a drop in the vertical distribution of root biomass within the soil as field capacity declines to 9% moisture content (fig. A.8a, b, c, d, e) (Asch *et al.*, 2005).



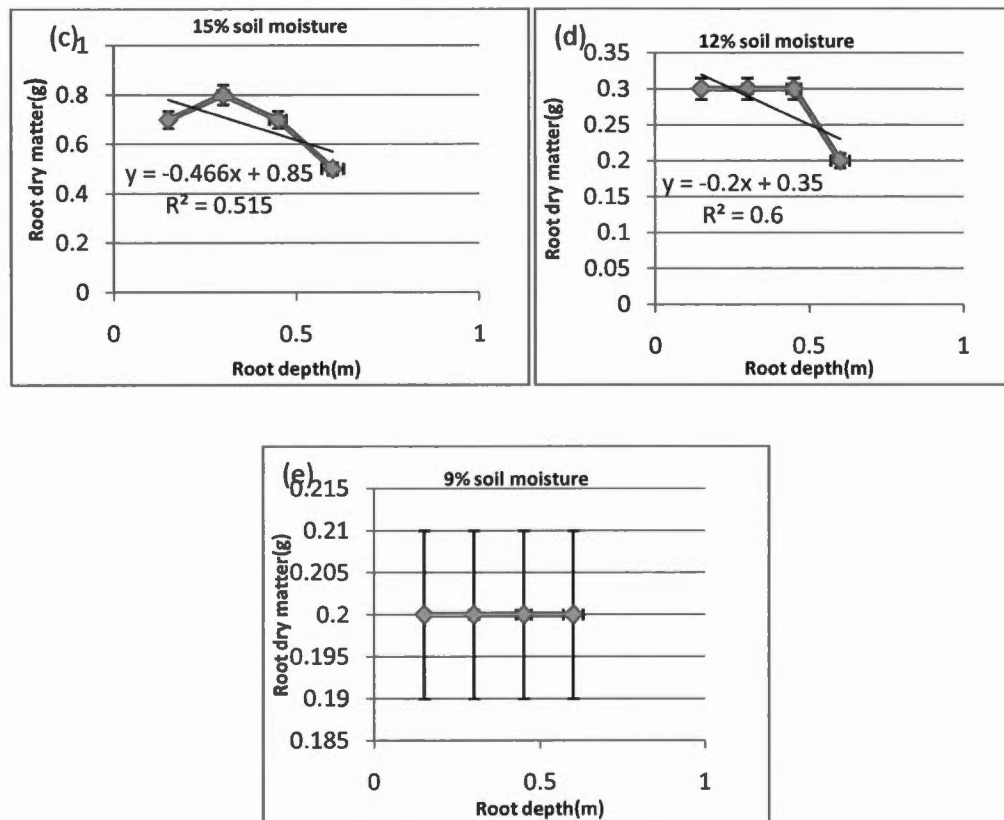


Figure A.8. Root dry matter distribution/rooting depth in the soil profile after 53 days of the experiment.

Source: Inspired from Asch *et al.*, (2005).

However, with indications of increase rainfall and vegetation in the Sahel since the 1990s, one is tempted to ask the question, why do we still have food problems in the Sahel? The answer to this lies in the fact that various human oriented activities do not make the available moisture available for agriculture (De Rouw 2004). Some of these activities include deforestation, cattle grazing, unsustainable farming and fuel wood fetching inter alia. As such, these have had a negative reinforcing feedback effect on the drought cycle and have made the droughts recurrent in the region. Therefore, this study holds that since human activities are at the forefront of the droughts, it only

suffices to synthesize that the trends in food production and tree mortality are principally caused by human activities which is also a key cause of the droughts.

A.6.Challenges, way forward and conclusion

1. Two major challenges that hamper the efforts at reducing food insecurity caused by droughts are internal political instability and public health concerns like HIV/AIDS and malaria. War and civil conflicts are common phenomenon in most of the Sahel as most countries in the region have been faced with civil conflicts (Antwi-Agyei et al., 2012; Olsson and Mryka, 2008). The challenges of HIV/AIDS and malaria are ravaging a huge portion of human capital and placing the population at the mercy of the food crisis (Muller, 2004; UNAIDS, 2002). In the Sahel, health and national security problems linked to HIV/AIDS and Malaria (Muller, 2004;UNAIDS, 2002) and civil wars (resource wars) such as the rush for diamonds in Angola are making it difficult for the people to effectively handle the effects of droughts especially on food systems. Therefore, combating these diseases and providing peace for most Sahelian countries would be a major way forward. Most of the countries affected by droughts (Mali, Niger, Sudan, Somalia, Ethiopia, Central African Republic inter alia) have either had wars or are being seriously affected by HIV/AIDS and malaria.
2. Another problem is the absence of adequate observations. In the future, long term observations will help fill in the gaps on inadequate climate, food production and ecosystem effects of tree mortality data. The available methods of simulation of climate, food production and tree mortality will make it possible to calibrate and validate models based on such long-term observations. Being that the droughts are recurrent, it is only through long term observations of rainfall, temperatures, food yields, tree species densities and tree species richness that the overall ecosystem shifts and long term adaptations can be applied.

3. Being that human activities are the main cause of the droughts, this study suggests the development of models that integrate both the natural and human oriented variables be perfected. Currently, most of the models and drought quantification indices have dwelled on the physical or climate related variables such as rainfall, temperature, evapotranspiration, transpiration at the expense of the human variables (see supplementary online section) (Palmer, 1965; Vicente-Serrano *et al.*, 2010; McKee *et al.*, 1993). One way out of this is by carrying out grass root studies that will assess the perceptions of local farmers and integrate the results in cumulative models that will enhance understanding by analyzing both the human and climate related variables (Giannini *et al.*, 2008). As such, future drought quantification efforts should aim at establishing indices that test both the climate and human oriented hypothesis against long term experimental and observational data sets (Leuzinger and Quinn Thomas, 2011; Zeppel *et al.*, 2011).
4. More studies need to be carried out on the critical levels at which moisture deficits occur, what time span constitutes a drought's duration and what a drought's threshold should be. Ecological studies on the deficits, durations and threshold limits of trees and grains needs to be integrated into drought modeling/forecasting indices. This will help in establishing the thresholds above and below which the species can no longer survive (Frelich and Reich, 2010). However, care must be taken to encompass regional disparities in environmental conditions and perceptions of what really droughts are to different people in different part of the world. In this situation, this study recommends the development of global models and subsequent testing of the latter against regional data to come out with regional models or indices that reflect the true drought deficits, durations and thresholds of the Sahel (Koepeke *et al.*, 2010).
5. Another way forward is to transform the entire system of farming in the region from extensive unproductive farms to intensive mechanized and

organic fertilizer farms (Epule *et al.*, 2012b). This approach is very important because this study has found out that the key problem is not with rainfall levels but the systems of farming and wide scale forest loss. The question now is will these measures be feasible in the Sahel region where poverty is rife? The suggestion that African farmers should take up the use of fertilizers should be treated with caution. This is because from the experience of the Asian agricultural revolution through which increase food production was attained from the application fertilizers; environmental repercussions of degrading water quality in streams was the order of the day (Epule *et al.*, 2012b; FAO and UNIDO, 2008). Therefore, investments in organic fertilizers and machines would be appropriate. However, being that poverty is rife in this region, other stakeholder levels of collaboration and funding such as with governments, nongovernmental organizations (NGOs), cooperatives and Reduction of Emissions from deforestation and forest degradation (REDD) should be reinforced (Lindell *et al.*, 2010a, b). In Peru for example, this has gained grounds and farmers involved in cooperatives are said to have a better understanding and potential of using organic fertilizers (Lindell *et al.*, 2010a, b; Rosegrant and Cline, 2003).

A.7.ACKNOWLEDGEMENTS

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APPENDIX B

CAN THE AFRICAN FOOD SUPPLY MODEL LEARN FROM THE ASIAN FOOD SUPPLY MODEL? QUANTIFICATION WITH STATISTICAL METHODS METHODS

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B.1. RÉSUMÉ

Cette étude cherche à vérifier les relations ou la corrélation entre les approvisionnements alimentaires et quatre variables qui sont les engrais, les machines, terre de culture et terre de pâture en Afrique et en Asie. Les données ont été obtenues à partir de FAOSTAT et de l'institut de ressource du monde (WRI). Les données ont été analysées avec la version 19 de SPSS. L'outil statistique de corrélation de Pearson et les méthodes multiples linéaires ont été utilisés dans l'interface de SPSS pour analyser les données. Les résultats montrent que les niveaux de l'application d'engrais et de l'utilisation de machines sont plus significatifs en affectant des approvisionnements alimentaires en Asie qu'en Afrique en ce qui concerne les quatre variables. En Afrique, la taille de la terre de culture est plus importante quand les approvisionnements alimentaires sont concernés et en ce qui concerne ces quatre variables. La tendance probable est pour que l'Afrique décrète les politiques qui encouragent les investissements en machines et engrais organiques à pouvoir améliorer sa production alimentaire.

B.2. ABSTRACT

This study seeks to verify the relationship or correlation between food supply and four variables which are fertilizers, machinery, permanent cropland and permanent pasture land in Africa and Asia. The data was obtained from FAOSTAT and the World Resource Institute (WRI). The data was analyzed with the SPSS version 19. Pearson correlation statistical tool and the multiple linear regression methods were then used within the SPSS interface to analyse the data. The results show that the levels of fertilizer application and machinery use are more significant in affecting food supply in Asia than in Africa with respect to the four variables. In Africa, permanent cropland is of greater significance when food supply is concerned and with respect to these four variables. The likely trend is for Africa to enact policies that will encourage investments in machines and organic fertilizers to be able to improve its food production and supply rather than merely increasing farm sizes.

Keywords: food supply, machinery, fertilizers, permanent cropland, permanent pasture land, food policy

B.3. INTRODUCTION

Agriculture is of great importance to mankind for the simple reason that people in all parts of the world need to be fed. In Africa, the importance of agriculture goes beyond just being fed to the fact that it contributes about 50% of the GDP (FAO and UNIDO, 2008). However, while regions like Asia have been able to transform their agricultural system to obtain 'increase food supply', Africa still lags behind and all we hear of Africa are reports of famine and food shortages (Yohanna, 2007). The Millennium Development goals were drawn with set targets to reduce by half the number of people who suffer from hunger by the year 2015. Yet, it is likely that this deadline is likely going to be reached without attaining a reduction in hunger especially in developing countries (Rosegrant and Cline, 2003; Matson *et al.*, 1997). In areas like Asia, Europe and North, America national governments have been able to reduce the number of people who face problems of food supply through astronomical increases in food production (Li *et al.*, 1997; FAO and UNIDO, 2008).

Food supply and production have often been considered as variables that are dependent on climatic factors such as precipitation, temperature and humidity, physiographic factors such as soil type, soil texture and slope to name but these (Kepner *et al.*, 1978; Van and Wold, 1986; Stewart, 1985; Bernstein and Pearson, 1954). However, there are several other important variables that impact on food supply and food. Some of these include the level of mechanization of pre and post-harvest agriculture, quantity of fertilizer used, sizes of permanent cropland and to a lesser extent pasture land (Rosegrant and Cline 2003; Bationo *et al.*, 1993; Matson *et al.*, 1997). Simply, physiological factors that impact crop yields have historically been balkanized into climate and soils. It is therefore true that where the soils are rich in compost, moisture and there is adequate temperature and sufficient rainfall, crop yields are likely to be good (Van and Wold, 1986; Stewart, 1985; Bernstein and Pearson, 1954; Antle *et al.*, 2004). This current study acknowledges the differences in the physiological factors that affect agricultural systems in both regions and the

fact that they vary. For the purpose of avoiding ambiguity and due to a lack of reliable time series data on soils and climate for the entire Asian and African regions all physiological factors are held constant or simply taken out of the analysis. This study seeks to verify the degree to which the use of fertilizers, machines, arable land and pasture land each correlates with food supply in Africa and Asia in an attempt to establish a clear picture of the current role of these variables in these regions and to specify how Africa can benefit from the Asian situation which as described in the literature is advanced (Bumb *et al.*, 1996). This approach is important because in spite of mankind's great understanding of the role of the physical factors, food crises remain ever so present. A look into the non physical dimension will go a long way to show where there are gaps and what examples are to be copied by lagging regions. Caution should be taken to understand that this study is not a comparison of the two regions which are evidently different in terms of the variables under study, cultural and the physical factors. To our knowledge, this is the first broad scale study that verifies the food supply situation in both Asia and Africa using essentially time series data.

Looking at the variables, it can be said that mechanization for example has been described as a very important component of agro-industrial development and its use varies from one landscape to another. It covers various farm equipments, irrigation and food processing techniques with the aim of increasing agriculture as a means of enhancing the productivity of human labour and to achieve results beyond the capacity of human labour (FAO and UNIDO, 2008; Matson *et al.*, 1997; Matson *et al.*, 1998; Antle *et al.*, 2004). In addition to the low productivity of essentially human labour driven farms, about 30-40 percent of crops are lost today in Africa due mainly to post-harvest problems such as lack of storage and processing facilities (FAO and UNIDO, 2008; De Datta, 1986; De Lima, 1987). It is for this reason that this study is focused on food supply in kilocalories per capita per day and not just the raw yields because emphasis so far has been on the raw yields with little attention at what

happens after harvest. As such, this study has defined food supply as the total amount of food that is available to the population from actual or raw yields and after subtracting food lost due to poor storage and inadequate processing. Therefore, food supply in the context of this study encompasses the actual or raw yields and the yields lost due to inadequate storage and processing. This can be summarized in the following food supply model: $FS = Y - YLS$, where FS is food supply, Y = actual yields before decomposition, YLS = yields lost due to poor storage and processing.

The application of fertilizers is another factor that has impacted agriculture in most developed and developing countries. Its importance in these study sites will be of great importance and its correlation to food supply will also be verified (Hossain and Singh, 2000; Buresh *et al.*, 1988; Matson *et al.*, 1998). The common types of fertilizers under consideration here are both organic (compost manure) and inorganic chemical fertilizers dominated by those of the nitrogen, phosphorous and potassium categories. Generally, the application of inorganic fertilizers should be done with caution and it is the place of governments to regulate this without which there will be long run environmental degradation due to seepage of pollutants in water systems, and general flora, fauna and soil degradation (Maeda *et al.*, 2003). This study therefore advocates a possible emphasis on compost fertilizers and a use of environmentally acceptable quantities of inorganic fertilizers to avoid the dangers of pollution. Finally, permanent croplands as well as pasture land are of pertinence. It is held that when crop and pasture land sizes increase food production and supply will increase since more hectares will come under cultivation. Here, this study will verify the correlation that this has to food supply in both regions (FAO and UNIDO 2008; FAOSTAT, 2011).

B.4. STUDY AREAS AND METHODOLOGY

The study area covers the entire Asian and African regions (figure B.1a and B.1b) with no exceptions of countries as it is specified on the websites of the World

Resource Institute (www.wri.org) and the Food and Agricultural Organization (www.faostat.org). Therefore, to obtain the data, we access the websites above and simply click on Asia or Africa, select the number of years for which data on the variable is available and select the variable, this way, the data is populated on an excel sheet directly. The data included variables such as food supply, machinery use, fertilizer use, permanent cropland and permanent pasture land. The time period covered by the data ranged from 1961-2000. Note that all the data used was time series data for all the five variables and they were obtained from FAOSTAT, (2011) and World Resource Institute (WRI), (2011).

The data was analyzed with the aid of the Statistical package for the social sciences (SPSS) version 19. Two main methods of analysis were applied. Firstly, the Pearson correlation statistical tool as specified in (Motulsky, 1999). The independent variables are machinery, fertilizers, permanent cropland, and permanent pasture land while the dependent variable is food supply. The equation used to run a Pearson correlation is given as follows:

$$r = \frac{\sum (x - \mu)(y - \mu)}{\sqrt{\sum (x - \mu)^2 \sum (y - \mu)^2}}$$

Where: r is the Pearson correlation coefficient, x is the independent variable, y is the dependent variable, μ is the mean of both variables, r ranges from -1.0 to +1.0 where: -1.0 to -0.7 strong negative associations, -0.7 to -0.3 weak negative association. -0.3 to +0.3 little or no association, +0.3 to +0.7 weak positive association, +0.7 to +1.0 strong positive association.

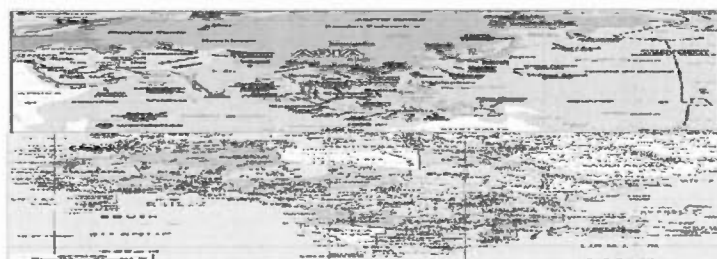


Figure B.1. (a) Asia and (b) is Africa

Source pulled from www.googlemaps.ca.

The second method of analysis was the use of the multiple linear regression tool as specified in (Motulsky, 1999). This method was employed to verify which of the independent factors was more responsible for the behavior of the dependent variable. The Equation used to fit the model is:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \epsilon$$

Where: y is the dependent variable, β_0 is the intercept, β_1 , β_2 , β_3 , β_4 partial regression coefficients, x_1 , x_2 , x_3 , x_4 are independent variables and ϵ is error term.

Based on the above methodology and background, this study seeks to answer the question, among the following variables (fertilizer use, use of machines, permanent crop land, permanent pasture land) which are more influential in explaining food supply for both Asia and Africa and which can we recommend African countries to invest in order to raise their food production?

B.5. RESULTS

In Asia, this study has observed that of the four variables under study, the quantity of fertilizers used remains the most important factor with respect to the variables included in this study affecting food supply in Asia (Figure B. 2 and B.7, Table B .1 and B.2). This is because it has a t-value of 12.461 which is by far higher than that for the other variables. In the same way, the coefficient of determination (r^2) and the Pearson correlation (r) for this same variable stand at 0.96 and 0.98 respectively. This is not only higher than the values obtained for the other variables but depicts a perfect positive correlation showing that as the quantity of fertilizers increase, so does the food supply (Figure B. 2). We can say that the quantity of fertilizers used aptly explains the behaviour of food supply in Asia. The rest of the variables in order

of importance are permanent crop land (t-value -4.045, r^2 0.87, and r 0.93) (Figure B.3), agricultural machinery (t-value 2.046, r^2 0.86 and r 0.93) (Figure B.4) and permanent pasture land (t-value -0.010, r^2 0.74 and r 0.86) (Figure B. 5). Therefore, while the use of fertilizers appears to be more important in Asia, the least important variable here is permanent pasture land (see table B.1 and B.2 and Figure B. 5).

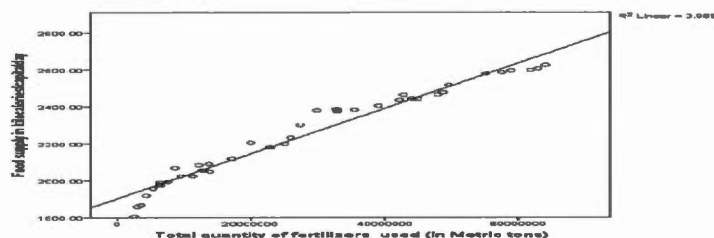


Figure B.2. Shows a close relationship between fertilizers and food supply in Asia. Points very close to the linear line depict that fertilizer use aptly explains the behavior of food supply. When compared to Africa (figure B.7) it is observed that Africa has a weaker correlation with food supply.

Table B.1. Correlation results for Asia

Independent variables	Dependent variable	Pearson's R	Level of significance
Permanent crop land	Food supply	0.93	0.01
Agricultural Machinery	Food supply	0.93	0.01
Total quantity of fertilizers used	Food supply	0.98	0.01
Permanent pasture land	Food supply	0.86	0.01

Table B.2. Results of Multiple Linear regressions, r^2 and r for Asia

Independent variables	Standard coefficients	Standard error	t-value	Rank of t-value	R^2	Rank of R^2	R&Ranks
Agricultural machinery	0.136	0.01	2.046	3	0.86	3	0.93-2
Quantity of fertilizers	1.443	0.01	12.461	1	0.96	1	0.98-1
Permanent cropland	-0.600	0.003	-4.045	2	0.87	2	0.93-2
Permanent pasture land	-0.001	0.001	-0.010	4	0.74	4	0.86-3

Permanent crop land and permanent pasture are expressed in thousand hectares and represents the area occupied by crops and agricultural animals. Agricultural machineries are expressed in thousand dollars of imports. Total quantity of fertilizers used is expressed in metric tons. Food supply is expressed in kilograms of calories per capita per day (Kcal/capita/day). Total observations = 40; $r^2 = 0.985$, Adjusted $r^2 = 0.983$; f-value 551.455.

While the use of fertilizers is an important variable that has led to increase food supply in Asia it is only considered a less important variable in Africa, showing that improvements have to be made in this area. Furthermore, in the area of machinery, Asia is also more advanced than Africa; this again shows why the gaps in food production and supply between these regions seem to be wide.

In Africa, farm sizes seen mainly in permanent crop land and permanent pasture land are more significant to food supply than is the case in Asia (Tables B.1, 2, 3, 4). Therefore, the most important variable for Africa out of the four used in this study is permanent crop land. This has a t-value of 3.515, r^2 of 0.95 and r of 0.97 (Figure B.6 and table B.3 and B.4). The other three factors in order of importance are quantity of fertilizers (r^2 0.91, r 0.95) (Tables B.3 and B.4, Figure B.7), permanent pasture land (r^2 0.71, r 0.84) (Table B.3 and B.4, Figure B.8) and agricultural machinery (r^2 0.58, r 0.76) (Table B.3 and B.4, Figure B.9). The t-values of these last three variables for Africa do not tally with those of the r^2 and r (see table B.3 and B.4). The regression analysis, r^2 and r show that permanent crop land is the most important variable while the use of machines in agriculture seems to be lowly rated by both methods.

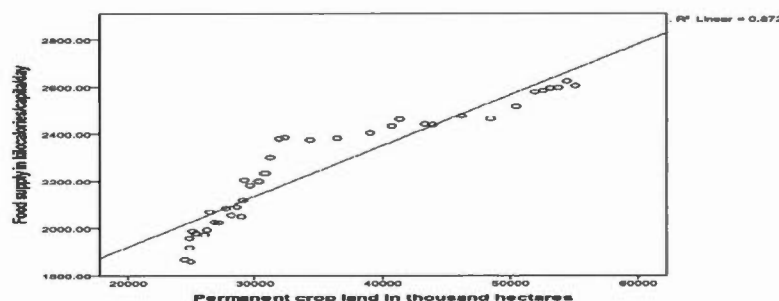


Figure B.3. Shows a close relationship between permanent cropland and food supply in Asia. Permanent cropland is second most important variable. When compared to Africa (figure B.6) it is observed that there is stronger relationship.

African permanent cropland increased by 64% (14868 thousand hectares) being that it was 27122 thousand hectares in 1961 and 41990 thousand hectares in 2000. In Asia, it increased by 43% (31087 thousand hectares) (55093 thousand hectares in 2000 and 24006 thousand hectares in 1961). In Africa, food supply increased by 324 kcal/capita/day (2029 kcal/capita/day in 1961 and 2353 kcal/capita/day in 2000) which is much lower than what was obtained in Asia during the same period (802 kcal/capita/day being that in 1961 it was 1804 kcal/capita/day and in 2000 it rose to 2606 kcal/capita/day). However, these figures should be interpreted with caution because of different population sizes and land areas under consideration in the different countries.

B.6. DISCUSSION

From the results, we can recall that the increase in machinery and fertilizers has been of great impetus in food production and supply in Asia while farm size increase seems to be more vital in the African food supply equation even though it has only had minimum positive effects. This is explained by the fact that Asia has for long had a food policy of food-self-sufficiency which encouraged large scale investments in fertilizers and machines while Africa has for long focused on labour driven production with a notion of large farms (Djurfeldt *et al.*, 2005). (This study therefore

recommends that African economies may be able to grapple with some of the problems of food insecurity and food supply by becoming a little more intensive by adopting the use of more organic fertilizers and machines. The national governments should supervise this and create credit schemes that will enhance farmer's access to the required knowledge and these resources.

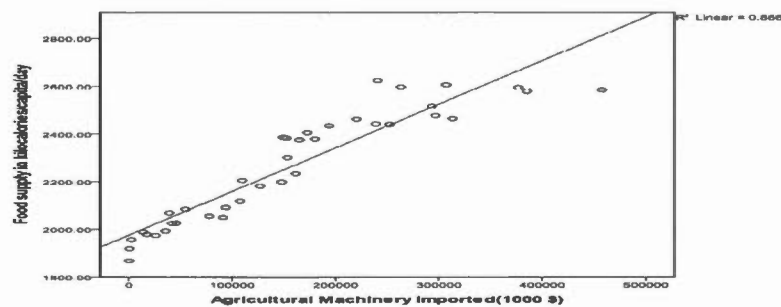


Figure B.4. Shows the correlation between agricultural machinery and food supply in Asia. Agricultural machinery is the third most important variable. When compared to Africa (figure B.9), it is observed that the relationship in Asia is stronger.

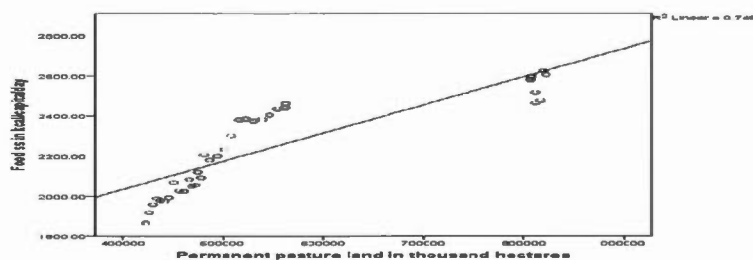


Figure B.5. Shows the correlation between Permanent pasture land and food supply in Asia. In general, this is the weakest variable in the entire simulation. When compared to Africa (figure B.8) it is observed there is a stronger correlation here than in Africa.

Table B.3. Correlation results for Africa

Independent variables	Dependent variable	Pearson's R	Level of significance
Permanent crop land	Food supply	0.978	0.01
Agricultural Machinery	Food supply	0.762	0.01
Total quantity of fertilizers used	Food supply	0.958	0.01
Permanent pasture land	Food supply	0.846	0.01

Table B.4. Results of Multiple Linear Regressions, r^2 and r for Africa

Independent variables	Standard coefficients	Standard error	t-value	Rank of t-value	R^2	Rank of R^2	R&Ranks
Agricultural machinery	0.097	0.01	1.278	3	0.58	4	0.76-4
Quantity of fertilizers	0.119	0.01	0.821	4	0.91	1	0.95-2
Permanent cropland	0.649	0.004	3.515	1	0.95	2	0.97-1
Permanent pasture land	0.165	0.001	1.969	2	0.71	3	0.84-3

Permanent crop land and permanent pasture are expressed in thousand hectares and represents the area occupied by crops and agricultural animals. Agricultural machineries are expressed in thousand dollars of imports. Total quantity of fertilizers used is expressed in metric tons. Food supply is expressed in kilograms of calories per capita per day (Kcal/capita/day). Total observations = 40; $r^2 = 0.962$, Adjusted $r^2 = 0.957$; f-value 213.327.

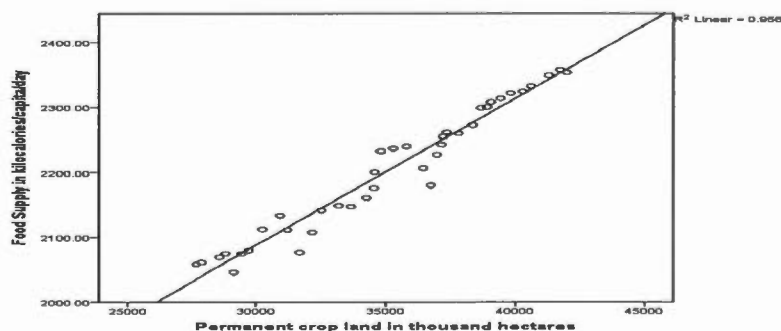


Figure B.6. Shows that in Africa permanent cropland is the most important variable affecting food supply. When compared to Asia (figure B.3) it is observed that this variable is of greater importance in Africa than in Asia.

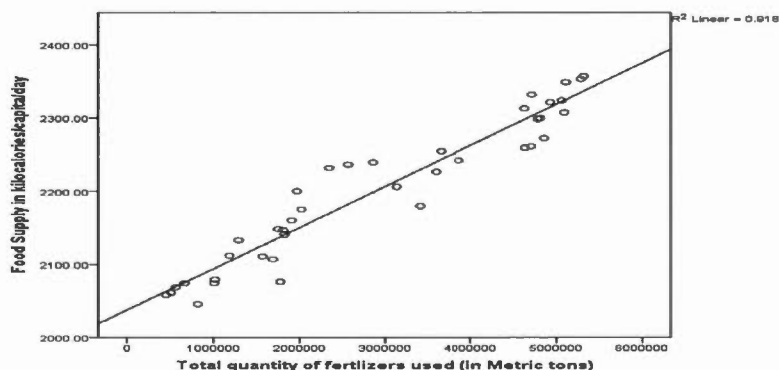


Figure B.7. Shows that total Quantity of fertilizers used in Africa are the second most important variable affecting agriculture in Africa. When compared to Asia (figure B.2) it is observed that the situation in Asia is stronger than in Africa as shown by the r and r^2 .

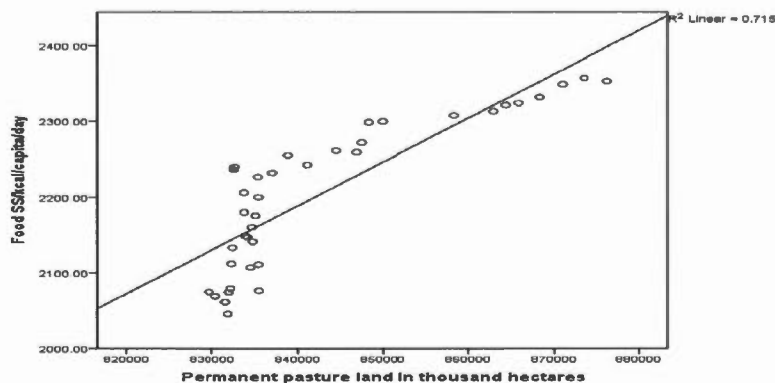


Figure B.8. Shows that permanent pasture land is the third most important variable in Africa. When compared to Asia (figure B.5), it is observed that this variable is of higher significance in Asia as seen in the r and r^2 .

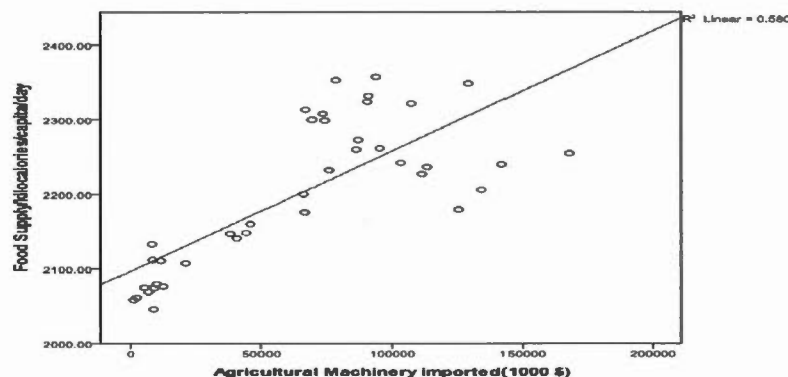


Figure B.9. Shows that in Africa agricultural machinery has the weakest correlation with food supply. When compared to Asia (figure B.4) the African situation is highly inferior as seen by the r and r^2 .

In the area of fertilizer application, the disparity is wide with Africa having 13kg/h and Asia having about 208 kg/ha (FAO and UNIDO, 2008). It has also been argued that famine was averted in Asia because of wide scale irrigation and the application of fertilizers. Comparatively, between 1988-1996 Asia had a rate of growth in fertilizer usage of 7.3 %/year while that of Africa was 0.4%/year; it is thus evident that fertilizer usage is higher in Asia relative to Africa and this explains why the scatter plot for Asia has its points closer to the trend line (Figure B. 1). In the global fertilizer usage chart, Asia's intake increased from about 45% between 1965-1966 to 53% in the mid 1990s (Hossain and Singh, 2000; Buresh *et al.*, 1988; De Datta *et al.*, 1990). Bationo *et al.*, (1993) and Abdoulaye and Sanders, (2005) also support the fact that low food yields in Africa are explained by low fertilizer use as shown by the effects of crop residue and fertilizers application on pearl millet yields in Niger.

At the moment, all statistics show that the gross intake of fertilizers in Africa is perhaps the lowest in the World. However, projections into the future hold that by 2020 Sub-Saharan Africa will be leading in fertilizer use with a rate of 3.3% annual growth rate; this will be far ahead of East Asia 1.9%, South Asia 2.8%, West

Asia/North Africa 1.9%, Latin America 2.3%, Developing countries 2.2% and Developed countries 0.2% (Bumb *et al.*, 1996). From these statistics, it can be observed that the trends are towards increase fertilizer use in Africa.

The issue of increase fertilizer and machine use in most of Asia has been an issue of the Asian regional agricultural policy of grain self-sufficiency under the auspices of the Green revolution. This became rampant in Asia in the 1960s as most Asian governments emphasized the need for grain self-sufficiency. As a result, this could either be achieved through an expansion of agricultural land or maintaining the current farm sizes but producing intensively. The latter was favourable for grain production and this resulted in small farms that were highly intensive in cultivation with the use of chemical fertilizers and machines (Djurfeldt *et al.*, 2005). On the other hand, agriculture in Africa from the colonial days to present is labour intensive and capital extensive; this explains why even when farm sizes increase, the net yields are low. In fact, the focus on human labour as a key element of food production in Africa has been the pillar of the agricultural policy; it is now time for governments to shift from such labour intensive policies to one that encompasses mechanization and a rational use of organic fertilizers (Djurfeldt *et al.*, 2005; Christensen and Larry, 1982).

Though the current increase in use of fertilizer in Asia relative to what obtains in Africa is good news for the Asian food supply economy, environmental critics have described this as damaging to the environment. The growing environmental concerns are raising fundamental changes in the importance attached to the use of fertilizers in food production with a major shift towards organic farming (De Datta, 1986; De Datta *et al.*, 1989; Hossain and Singh, 2000). The recent global decline in fertilizer use is associated to declines in the former USSR and Europe and is due mainly to environmental concerns with an increasing demand for organic farming (Rosegrant and Svendsen, 1993). To be concrete, recent studies conducted in the Subandean

Amazon of Peru have shown that the need to establish new farming plots and to increase yields has led to an increase in the demand for chemical fertilizers and pesticides. While this is argued as being good for the yields, these studies also note that with a lack of functional riparian zones, there is a high level of risk for the degradation of soils and water systems in the long run (Lindell *et al.*, 2010abc). These views have been supported by studies on chemical fertilizers that have degraded soils in Bolivia and West Amazonian (Abe *et al.*, 2007; Araujo *et al.*, 2004).

The question now is, with the cost associated to organic farming, will African countries be able to invest in organic farming? if they do, will the middle class African family be able to meet their food needs? Should African countries now concentrate on organic farming rather than investments in fertilizer use and machinery? The answers to these questions are complex. While it is proposed that African countries increase their use of fertilizers, this study argues that due to the environmental short comings reported above, the solution will come from whether Africans adopt the use of organic fertilizers or not. In fact, in Peru, it has been reported that farmers who were involved in cooperatives had a better understanding and potential of using organic fertilizers because the cooperatives they belonged to organized this for the farmers (Lindell *et al.*, 2010abc). It therefore means that, it does not help to simply say investments should be made in fertilizer, the types must be specified and the means should be put in place to get the organic fertilizers to the farmers, in most cases this is most effective through cooperatives as seen above.

In Asia, there have been more advances in mechanization of agriculture and this has been responsible for the rapid increase in food supply while Africa is still lagging behind (World Bank 1987; FAOSTAT, 2011; FAO and UNIDO, 2008). In Africa, it has been argued that mechanization of agriculture is either facing stagnation or retrogression (FAO and UNIDO, 2008; Kepner *et al.*, 1978). The reasons for this stagnation and retrogression are the absence of sound strategies and policies of

mechanization such as investments in tractors and other farm management schemes such as irrigation, lack of coordination between government and private sector (Yohanna, 2006; FAO and UNIDO, 2008). When Africa excluding South Africa, Egypt and Mauritius is compared with 9 Asian countries, we observe stagnation in agricultural production and food supply in the 1970s and 1980s where cereal yield for Africa has stagnated at about 1 ton per hectare or 1040kg/ha while that of Asia is about 3348kg/ha. At the same time, the number of tractors in Africa stands at 28 per/1000/ha while that of Asia stood at 241 per/1000/ha (Reid *et al.*, 2003; FAO and UNDO, 2008). It is further reported that increase mechanization would lead inter alia increase food production, improved land use, enhanced rural prosperity and greater exports and less reliance on imports (Yohanna, 2007; FAO and UNIDO, 2008, FAOSTAT, 2011). In 1798, Malthus advocated the principle of preventive checks in his book, 'An Essay on the principle of population'. Preventive checks are reflected in the area of investments that would prevent famine and subsequent population decline. Such checks in today's world would include machines and fertilizers that would enhance productivity (Rosegrant and Cline, 2003).

As concerns permanent cropland, it is observed in the results that the farm sizes in Africa have not doubled between 1961 and 2000 while those of Asia have almost doubled during the same period (FAOSTAT, 2011). In the case of Africa, farm size increase has been the main cause of the minor increase in food supply presented in the results above (FAOSTAT, 2011). In fact, Rosegrant and Cline, (2003) argue that expansion of agricultural land or cultivated area is one means of boosting up production that is sufficient to meet rising demands. The process of increasing land in order to cultivate more crops is not sustainable for the environment. This is why; it has been argued that arable and permanent crop land increase in Cameroon for example to enhance crop production has been described as the second most vital cause of deforestation (Epule *et al.*, 2011). In Asia, the changes in land sizes presented in this paper have been seen as the second vital factor that correlates with

food supply during the same period. This increase is mainly accounted for by agricultural intensification; however, permanent crop land is also of importance in explaining the observed trend (Zhao *et al.*, 2006). It can be said that, permanent crop land is of importance in both regions in effecting food supply but the response has been more positive in Asia than in Africa probably because Asia has invested more on fertilizers and agricultural machines. In Asia, permanent pasture land is less important when compared to the situation in Africa; this is seen in the differences in the slopes of the curves where in Africa the points for permanent pasture land are closer to the trend line than in Asia (Figure B.4 and B.7).

In a nutshell, these results should be considered with caution because the multiple linear regression models were fitted inconsideration of the following variables (fertilizers, machines, permanent crop land and permanent pasture land. It can be argued that several other factors such as rainfall, temperatures, soils, cultural setting and political instability can influence food supply (Van and Wold, 1986; Stewart, 1985; Bernstein and Pearson, 1954; Antle *et al.*, 2004). It suffices to say that this study acknowledges the role of all these other variables but the interest here is to see how the four specified variable affect food supply. The methods of correlation analysis and multiple linear regressions are suitable for such analysis as they ease specification of variables to test the behaviour of specific variables with the knowledge that many variables may affect a phenomenon under study (Motulsky, 1999).

B.7. CONCLUSIONS

The evidence provided by this study shows that fertilizers and machinery are very important factors that affect food supply in both Asia and Africa and that Africa could revamp its food supply by increasing its investments in agricultural mechanization and the application of organic fertilizers. This does not the least mean that the other variables do not play a role. In Africa for example, permanent cropland is also another variable though its effects on food production is minimal. Though it is

therefore advocated that African countries work towards increasing their fertilizer and machinery use, the unanswered questions are how will the environmental degradation resulting from fertilizer application be handled? As such, this study proposes the adoption of organic fertilizers and farm mechanization by African economies with the governments coordinating to see that farmers get subsidies and are educated on the use of organic fertilizers and the dangers of chemical fertilizers. Furthermore, this study recommends that other studies be carried out on smaller scales to tests the results presented here and if possible the influence of other factors that affect food production and supply be incorporated.

B.8. ACKNOWLEDGEMENTS

Special thanks go to the Natural Science and Engineering Research Council of Canada discovery grant and the Fonds à l'accessibilité et à la réussite des études – (FARE) of the University of Quebec in Montreal for funding this study.

Appendix B1

Table B.5. Raw Data used in assessing the Asian food supply model

Years	Food supply in kcal/capita/day (y)	Agricultural Machinery imported(1000\$) (x1)	Total Quantity of fertilizers used (in Metric tons) (x2)	Permanent crop land in thousand hectares (x3)	Permanent pasture land in thousand hectares (x4)
1961	1804.76	220	2588668	24006	416992
1962	1858.69	331	3020607	24900	420018
1963	1867.9	226	3592249	24451	422972
1964	1918.55	581	4356839	24826	426354
1965	1956.99	2366	5385459	24813	430571
1966	1988.83	13807	6440727	25049	434598
1967	1978.59	17398	6366671	25329	437899
1968	1974.15	26039	6459101	26008	441794
1969	1993.25	35706	7642173	26182	446279
1970	2069.18	39353	8724031	26425	451001
1971	2026.14	46211	9677379	26787	456099

1972	2024.67	41925	11412688	27121	460820
1973	2084.36	55038	12274073	27671	466544
1974	2056.16	78105	12831264	28101	472729
1975	2091.51	93961	13760341	28602	478644
1976	2050.42	91423	13908383	28971	469127
1977	2119.68	108165	17176384	29114	475372
1978	2205.7	110116	19916777	29222	481210
1979	2181.25	127451	22815782	29667	486703
1980	2200.06	148389	25073705	30348	494485
1981	2233.21	161631	25879982	30805	501404
1982	2301.51	153680	27377365	31180	508437
1983	2380.83	180487	29837374	31889	516783
1984	2386.6	149628	32755117	32341	522742
1985	2375.97	165315	32884891	34306	530347
1986	2383.45	152836	35496636	36434	538703
1987	2404.84	173135	39042504	39033	546556
1988	2435.22	194130	42234039	40711	554707
1989	2463.06	220351	42832992	41345	562546
1990	2443.35	239174	44158415	43309	562331
1991	2441.11	252460	44922829	43941	561685
1992	2477.28	296883	48722914	46199	816468
1993	2464.85	313526	47976985	48473	811780
1994	2516.95	293448	49611601	50467	811586
1995	2578.77	385389	55191549	51929	807050
1996	2584.7	457570	57561926	52569	807004
1997	2595.24	376993	58931627	53134	807798
1998	2597.62	263341	61863717	53764	807991
1999	2624.67	240828	64082894	54444	819782
2000	2606.13	307298	62922312	55093	822357

*the data on this table is for the entire Asian region as found on www.faostat.org

Appendix B2

Table B.6. Raw Data used in assessing the African food supply model

Years	Food supply/kcal/capita/day (y)	Agricultural Machinery imported (1000 \$) (x1)	Total Quantity of fertilizers used (in Metric tons) (x2)	Permanent crop land in thousand hectares (x3)	Permanent pasture land in thousand hectares (x4)
1961	2029.94	1060	394288	27122	833827
1962	2058.48	1160	451391	27678	832626
1963	2061.34	2337	511457	27914	831552
1964	2069.25	6835	566665	28606	830388
1965	2074.85	5336	668723	28844	829621
1966	2045.87	8911	818595	29152	831875
1967	2074.66	9196	1009207	29462	831981
1968	2079.36	10048	1016908	29732	832169
1969	2112.16	8477	1185269	30264	832292
1970	2133.38	8209	1293541	30924	832431
1971	2111.11	11743	1572057	31216	835456
1972	2076.58	12578	1776412	31688	835473
1973	2107.31	21167	1691418	32166	834541
1974	2141.09	40820	1826696	32520	834767
1975	2148.52	44482	1751765	33192	833909
1976	2147.02	38248	1810732	33668	834183
1977	2160.25	46104	1910712	34264	834668
1978	2175.58	66679	2022714	34554	835096
1979	2200.15	66139	1969305	34578	835478
1980	2232.3	75566	2352554	34818	837057
1981	2236.69	113588	2573180	35292	832583
1982	2239.88	142286	2863279	35804	832660
1983	2206.4	134499	3137522	36444	833767
1984	2179.94	125858	3412138	36746	833780
1985	2226.81	111642	3599742	36982	835361
1986	2255.05	167848	3658102	37224	838846
1987	2242.41	103443	3865099	37158	841137
1988	2261.67	95283	4708028	37358	844527
1989	2259.88	86272	4636644	37812	846882
1990	2272.77	86854	4860401	38364	847489
1991	2298.97	73999	4783410	38676	848316

1992	2300.09	69277	4814894	38920	849993
1993	2307.92	73221	5094078	39062	858357
1994	2313.5	66968	4630679	39432	862935
1995	2321.67	107608	4929240	39812	864373
1996	2324.33	90501	5063950	40292	865851
1997	2332.18	90922	4715421	40602	868305
1998	2349.05	129537	5110960	41296	870983
1999	2357.53	93792	5319362	41724	873548
2000	2353.35	78284	5287128	41990	876265

*the data on this table is for the entire African region as found on www.faostat.org

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APPENDIX C

METHANE EMISSIONS FROM PADDY RICE FIELDS: STRATEGIES TOWARDS ACHIEVING A WIN-WIN SUSTAINABILITY SCENARIO BETWEEN RICE PRODUCTION AND METHANE EMISSION REDUCTION

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C.1. RÉSUMÉ

Cette étude synthétise les émissions du méthane des gisements de riz non-décortiqué et les diverses stratégies qui peuvent être employées pour atténuer l'émission de méthane tout en continuant la production de riz. L'option d'installer une approche avantageuse pour les deux parties de développement durable est basée sur le fait que le riz reste l'une des céréales le plus consommées dans le monde. L'étude cherche également à faire un synthèse des mécanismes d'émission et à illustrer que quand les émissions de méthane sont hautes dans des états d'inondation (saison des pluies), il y a une réduction de récolte de riz et l'inverse est vrai au cours des périodes de moins d'inondation. Cependant, comment le riz peut-il être produit sans inondation? Les résultats de l'analyse et de l'examen montre que, globalement, le Sud-est d'Asie est le premier dans la production mondiale de riz et les émissions de méthane. Pendant les périodes d'inondations les émissions sont élevés et cela compromet les rendements du riz. La solution optimale de l'atténuation est basé sur une synergie des méthodes et pas seulement sur une seule méthode comme on l'a vu dans l'examen des stratégies d'atténuation.

C.2. ABSTRACT

This paper reviews the emissions of methane from Paddy rice fields and the various strategies that can be used to mitigate methane emission while continuing with rice production. The option of setting up a win-win sustainable development approach is based on the fact that rice remains one of the most widely consumed cereals in the world. The paper also seeks to review the emission mechanisms and to illustrate from existing literature that when methane emissions are high under flood conditions (rainy season), there is a reduction in rice output and the reverse is true during periods of less flood. Yet, how can rice be produced without flooding? This paper is mainly a review paper which essentially obtains most of the information by reviewing other studies. The results of this analysis and review shows that globally, South East Asia leads in the global rice production and methane emissions chart. During periods of floods emissions are high and this compromises rice yields. The optimum solution to mitigation is based on a synergy of methods and not just on a single method as seen in the review of mitigation strategies.

Keywords: methane emissions, paddy rice yields, win-win sustainability

C.3. INTRODUCTION

Methane is a vital greenhouse gas and its atmospheric concentration has almost increased three fold since the pre-industrial era (Keppler *et al.*, 2006; Zou *et al.*, 2005). Methane is further important because emissions of about 1 kg of methane to the atmosphere are 21 times more destructive to the radiation balance than does 1 kg of carbon dioxide (Denier *et al.*, 2002). As a cause of climate change, methane is only second to carbon dioxide as its global warming potential is 23 times greater than carbon dioxide on a mass balance basis (Towprayoon *et al.*, 2005; Intergovernmental Panel on Climate Change (IPCC), (2001). Furthermore, the desire to consider Paddy rice fields is pertinent because rice remains a vital crop as it is grown on more than 150 million hectares of land globally and humans consume more rice than any other cereal globally (Bloom and Swisherm, 2010).

Paddy rice fields now constitute a predominant source of anthropogenic atmospheric methane (CH₄) (Agnihotris *et al.*, 1998). Other sources are enteric fermentation, natural wetlands, landfills, coal mining, gas production and distribution, biomass burning and oil exploitation and distribution. While it is certain that these are the main sources, the relative contribution of the different sources to the global picture remains an issue of high uncertainty (Aselmann and Crutzen, 1987; Zou *et al.*, 2005).

Continual intensification of Paddy rice cultivation will contribute to the gradual rise in atmospheric methane (Inubushi *et al.*, 2001). In addition, a seasonal pattern of variations in methane emissions is observed for Paddy rice fields when compared to fields that are rice free. This is because rice plants stimulate methanogenesis under submerged conditions in the wet season which enhance methane production (Denier *et al.*, 2002).

C.4. OBJECTIVES AND METHODOLOGY

From the aforementioned, this study seeks to use a desk study approach by reviewing existing literature on the contributions of Paddy rice methane emissions to the global methane emissions picture, a review of the seasonal variations in methane emissions with Paddy rice yields. This involves methodological hypothesis validation based on evidence in existing literature that there is an inverse relationship between methane emissions and Paddy rice yields and to review the mechanisms that can be used to reduce Paddy rice methane emissions while at the same time still producing rice (win-win sustainability). The main methodological concept therefore is the 'win-win sustainability' that describes a scenario in which development and environmental protection go hand in hand. In the context of rice production, this means that current production of rice should not be done at the expense of wide scale methane emissions. On the other hand, the desire to reduce methane emissions should not be at the expense of rice production. In a nutshell, rice production should be carried out such that it is enough to meet population needs on the one hand while mitigation strategies should be put in place to curb methane production. While acknowledging the fact that persistent methane emissions will compromise future rice production, win-win sustainable development is one in which current development endeavours enables the needs of current generations to be met without compromising the ability of future generations to meet their own needs, this study aims at reviewing the approaches that can be put in place to attain such a goal (Brundtland, 1987).

C.5. RESULTS AND DISCUSSION

C.5.1. Paddy rice methane emissions in the Global methane emissions picture

Globally, most of the methane emissions from Paddy rice fields do occur in and around the tropics, sub-tropics and parts of the temperate boreal. This includes areas like Central and Latin America, Africa and South East Asia (Figure C.1 and C.3 below) (Aselmann and Crutzen, 1987). South East Asia emits approximately 10 000

kg of methane per kilometer square or contributes 90 % to the global rice methane emissions chart (see rectangle on Figure C.1) (Yan *et al.*, 2009; Aselmann and Crutzen, 1989). Africa and South America add 3.5% and 4.7% to the global Paddy rice methane budget respectively. Within South East Asia, India and China are also the two major dominant rice producing countries (Aselmann and Crutzen, 1989). So, the areas of high rice production are equally the area of high methane emissions due to rice cultivation (Yan *et al.*, 2009).

The global distribution of rice Paddies varies with latitudes. Most of the cultivation of rice is within latitudes 50° N and 30° S of the equator (Aselmann and Crutzen, 1989). If we correlate this spatial distribution of Paddy fields (Figure C.3) with the zones of rife annual Paddy rice methane emissions (Figure C. 1) we observe that the two zones represent the same region. We can therefore say that most of the zones of high Paddy rice production are equally the zones of high Paddy rice methane emissions and these are principally in the Northern hemisphere as elaborated already.

The total global methane emissions from all sources stand at about 600 Teragrams per year (Tgyear^{-1}) (Denier *et al.*, 2002). Estimates of Paddy rice contributions to the global methane budget have been set at approximately 10 % (Figure C.2) and 15 % (Global Methane Initiative (GMI), 2010) and Inubushi *et al.*, 2001) respectively. These estimates are relatively good because their variance of 5 is not too large being that they are independent studies. The main weakness of these estimates is that enteric fermentation is considered as an independent contribution to the global chart, yet enteric fermentation is a process that takes place during rice production in flood waters.

Currently, the rate of emission of CH₄ from rice fields is rising at an annual rate of 0.7-1.1% per year. This is translated to about 18-280 Teragrams per year (Tg/Y⁻¹) which is equal to 10-70 % of anthropogenic methane (Agnihotris *et al.*, 1998). Aselmann and Crutzen, (1989) also set the rate of emission at 60-140Tg of CH₄Y⁻¹. Most of these estimates have not been obtained using the IPCC guide lines. Using the IPCC guide lines and country specific activity data, Yan *et al.*, (2009) observed that global Paddy rice fields would emit 25.6 Tg a⁻¹. This has a 95 % certainty range of 14.8-41.7 Tg a⁻¹. This study observes that the wide degree of possible CH₄ emission levels heralds the notion of large degrees of uncertainty in the methods. For this reason, Aselmann and Crutzen, (1989) propose the use of ecophysiological studies which increase certainty.

C.5.2. Mechanisms of Paddy rice Methane Emissions and seasonal variations in methane emissions and Paddy rice yields

The main vectors behind methane emissions from Paddy rice fields are methanogenic bacteria. Methanogenic bacteria can be divided into myxotrophic, obligate chemolithotrophic and quasi-chemolithotrophic microorganisms. Such microorganisms perform well under anaerobic conditions and are responsible for harvesting organic carbon and transforming it into methane, this process is called methanogenesis (Bloom and Swisher, 2010; Inubushi *et al.*, 2001). The anaerobic conditions are the biochemical pathways of methane production. The source materials for all these reactions are the straws of rice plants which represent the main inputs of organic materials. These materials normally build up and during the rainy season or periods of inundation they decompose and become the main source of methanogenic substrates. As such, the carbon that is not available for seeding is emitted into the soils and is transformed into methane by methanogenic bacteria (Denier *et al.*, 2002; Naser *et al.*, 2007).

Later, other sources of organic carbon such as newly produced plant residues will gain importance. Once the methane is produced from the methanogenic processes it is now transported vertically to the atmosphere through three main pathways. These pathways include diffusion of dissolved methane that reaches the flooded waters, the emergence of bubbles triggered by soil fauna and crop management procedures and finally plant transport by diffusion into the roots and conversion to gaseous methane in the cortex and aerenchyma and subsequent release of methane to the atmosphere through plant micropores (Figure C.4) (Wassmann *et al.*, 1993).

Methane emissions from Paddy rice fields tend to follow a seasonal pattern. This means that in the rainy season emissions are higher while at the same time there has been observed reductions in rice output. On the other hand, during the dry season methane emissions are lower and irrigated Paddy fields tend to experience a bumper crop. However, the notion of dry season rice farming does not mean a complete absence of water which will rather have negative effects on rice yields. Emphasis is on cultivation in swampy areas which are less flooded than the wet season fields and have just enough water for survival of rice. As such, the common hypothesis now is that there is an inverse correlation between CH₄ emissions and grain yields. Several studies have verified this hypothesis. Firstly, it has been observed that the harvest index (HI- which represents the mass ratio of grain output and the total above ground biomass) is lower in the wet season when methane emissions are high than in the dry season when methane emissions are lower for rice plants (Corton *et al.*, 2000).

In general, cereal output is limited by the supply of assimilates to fill the grains called source limitation and the ability of the reproductive organs to take up the assimilates called sink limitation. The latter is common in rice in the wet season while the former is common in the dry season when the flower clusters are very high. Results from modeled simulations now show that sink limitation does not occur in the dry season

but rather showed lower HI values in the wet season with more sink limitation. It is argued that low solar radiation during the preanthesis period results in reduced assimilate supply and the degeneration of spikelets which may lead to a reduction in yields and HI in the wet season while in the dry season, yields and HI are higher (Denier *et al.*, 2002).

Studies have proven that during the wet season methane emissions are high while during the dry season, methane emissions are low. At the same time, yields are low during the dry season and high during the rainy season (Figure C.5). This is explained by the fact that in the wet season, the resultant photosynthesis produces carbon but a shortage of flowers and spikelets makes this carbon not to be available for grain production and therefore low rice output. This amount of carbon not available for seed production gets into the soil as rhizodeposition and as leaf litter fall where they serve as raw material for methanogens, thus, high methane emissions in wet season. In the dry season scenario, much of the carbon is used for seeding and active rice production, thus, a lower methane emission and higher rice output (Sass *et al.*, 1990; Denier van der Gon *et al.*, 2002). The above findings are consistent with the observations of Pschorn *et al.*, (1986) who argue that a seasonal change of daily mean CH₄ emission rates from flooded fields between May 3 and September 13, 1985 for three field types (Paddy rice field, field planted with weeds and field which was kept unplanted) showed a variation in emissions as follows: 36.3, 18.4 and 20.1 g m⁻² for the Paddy rice field, the weed field and the unplanted field respectively. This shows that the Paddy rice field section experienced more emissions of CH₄ than the other two sections under flooded rainy season conditions (Figure C.6). Similarly, results from laboratory experiments carried out by Pschorn *et al.*, (1986) are also consistent with the field experiments presented above. The laboratory experiments hold that there is increased methanogenesis and production of CH₄ when we have rice fields which are submerged than with unvegetated submerged soils (Pschorn *et al.*, 1986).

3.3 Agricultural practices to reduce methane emissions from Paddy rice fields

It has been noted that as human populations continues to increase; the need for more rice cultivation becomes even so evident. With this, there is a parallel risk of more methane emissions. However, if a sustainable society has to be maintained then a win-win situation has to be established. This means that strategies to curb methane emissions must be put in place but these must not be at the expense of rice production. If the latter is the case then, the very notion of sustainability would have been defeated (Brundtland, 1987). This part of this study therefore looks at the different techniques that can be used to reduce methane emissions from Paddy rice fields.

C.5.3. Water management methods

Water management has been considered as one of the methods that can be used to reduce methane emissions from Paddy rice fields. Intermittent drainage for example has the advantage of improving oxidative soil conditions by promoting root activity, increases soil bearing capacity and ultimately reducing excess water that causes anaerobic conditions and will also introduce oxygen into the soils thus rendering the area aerobic and also reducing the formation of methane. Mid season drainage enhances nitrogen absorption as well as soil oxidative conditions (Inubushi *et al.*, 2001). In other words, this could be carried out by reducing the amount of water applied to the fields since a net decrease will reduce methane emissions. However, caution will have to be taken to ensure that the water requirement of modern day rice plants is maintained. This is set at approximately 6 mm per day; lower levels will be very adverse for rice cultivation (Wassmann *et al.*, 1993; Wassmann *et al.*, 2000; Naser *et al.*, 2007).

Closely linked to the water management method is the control of the pattern of flooding of irrigated rice (creating temporal dry periods). This would include short term droughts and is of great value because rice plants can recover from relatively brief periods of moisture stress if suitable conditions are quickly reestablished. In most parts of South East Asia, this method has been tested and the yields have been almost equal. However, the reaction to moisture stress varies with the stages of development in the rice plant. Research has shown that pre-flowering stages appear more tolerant to moisture stress while the flowering and grainning stages are more sensitive to this technique (Wassmann *et al.*, (1993). Therefore, a pattern that considers the water requirements of the rice plants at the different stages would be plausible. Whatever the case, it has been argued that creating such temporal dry periods to curb methane emissions will often result in increased nitrification and denitrification with a net loss of nitrogen (Wassmann *et al.*, 1993). Bloom and Swisher, (2010) argue that water management practices that drain rice fields in the middle of the growing season to cut down methane by 15% to 59% depend on the availability of additional water to re-flood the Paddies and add about 5-9% more to the cost of production (Bloom and Swisher, 2010; Li *et al.*, 2005).

Another water management technique is the shift in rice cultivation from wetlands to upland rice cultivation. It has been argued that this will certainly reduce flooding and methane emission but will be of adverse effect to rice yields since yield under dry land conditions are generally much lower than in wetland rice Paddies. According to Wassmann *et al.*, (1993) and Li *et al.*, (2005) this technique is far from being feasible because most upland rice varieties yield about 1 ton per hectare (t/h), the modern rice varieties cultivated in upland areas yields about 4 t/h. He argues that this compares weakly to the 7 t/h for swamp or irrigated or flooded rice. However, Towprayoon *et al.*, (2005) argues that even though drainage reduces methane emissions, it is capable of enhancing Nitrous oxide emission which can reduce yields. This can be established

as a wicked problem where one solution creates another problem, the reason why a synergetic or systematic approach is advocated.

C.5.4. Soil Additives

Furthermore, the application of organic matter is an important factor. This will also enhance aeration and will further cause an increase in the growth of aquatic weeds. However, this method of draining the land is currently weakened by the fact that, current findings from weeded pots on which Paddy rice was grown show that when aquatic weeds take over they may cause an increase in methane emissions in the long run (Inubushi *et al.*, 200). The mechanism by which this happens is not yet well understood. Inubushi *et al.*, 2001, have investigated the potential of weeds in Paddy fields to produce methane and have observed that fields under weeds do produce more methane than those under no weeds. This method can therefore be effective if application of manure is accompanied by frequent removal of other invasive weeds.

It is argued that the current surge of emissions of methane from terrestrial plants is not properly understood (Schiermeier, 2010). In attempting an explanation it is observed that the emissions cannot be from bacteria activities in the leaves or enzymes of plants in plant cells. They suggested that plants produce methane autonomously without a catalyst such as protein. Instead, the chemical pathway involves pectin. The different sugars in the molecules of pectin are used by plant cells and are constantly being synthesized and degraded and this to them could produce methane. However, the exact mechanisms by which this works are still unclear (Keppler *et al.*, 2006; Wassmann *et al.*, 2000).

Another soil additive method used in controlling methane emissions from Paddy rice fields is by controlling the input of straws from rice into the flooded soils. Most of the methane produced is from the decomposition of the rice straws that are often in

flooded water. This is done by making sure that the rice straws are not allowed to decay in the flooded water since this will favour the growth of methanogenic bacteria. According to Nagata, (2010) the rice straws can be used as feed for cattle while the composted animal manure from the cattle is applied to the Paddy fields as has been the case in Japan. This will invariably increase plant nutrients, retain plant nutrients, increase production stability and quality of rice, decrease methane emissions, promote rice growth and encourage aggregate soil structures. A view supported by Kulshreshtha and Singh, (1998). This has been illustrated on Figure C.7.

Again, soil amendments could be of great importance in the fight to reduce methane emissions from Paddy rice fields. One way of doing this is through the application of nitrification inhibitors to Paddy soils. Inhibitors such as acetylene and nitrapyrin have been known to have the potential of inhibiting nitrifiers, methanogens and methane oxidizers. Though the ability of nitrapyrin to reduce nitrification has been questioned, recent experiments have shown that encapsulated calcium carbide from which there is a slow release of acetylene to the soil is efficient in the reduction of methane emissions from an artificial Paddy system in a greenhouse. Other studies have also shown a 30% increase in rice yields with increase acetylene (Wassmann *et al.*, 1993; Yan *et al.*, 2005).

Furthermore, soil amendments geared towards reducing methane emissions could be attained through the application of sulfates. Denier *et al.*, (2001) argue that the application of sulfate fertilizers is often suggested as an amendment method. However, this is not able to reduce methane emissions by 100%. They argue further that for all the experiments carried out, reductions in methane emissions following the application of sulfates was observed. This is explained by the fact that in the presence of sulfates, sulfate reducing bacteria (SRB) will out-compete methanogens (methane producing bacteria-MPB) for substrates and this will reduce CH_4 . Both SRB and MPB compete for the same substrates such as $\text{H}_2 + \text{CO}_2$ or acetate that MPB

use in methane production (Pschorn, *et al.*, 1986; Yan *et al.*, 2005; Zou *et al.*, 2005). However, there was never a complete inhibition of methane emissions from rice fields following the application of sulfates because the maximum reduction of methane emissions that can be obtained in rice fields is in the range 60-70% no matter the amount of sulfates applied. Also, reductions in CH₄ at 100% could be further difficult because CH₄ emissions are not controlled only by CH₄ production but also by CH₄ oxidation and by the gas transport pathways to the atmosphere such as diffusion, ebullition and also related transport (Denier and Neue, 1994). Uncertainty in this approach is created when Wassmann *et al.*, 1993; Wassmann *et al.*, 2000; Yan *et al.*, 2005) report that experiments with the application of nitrogen and sulfate fertilizers in an attempt to observe the behaviour of methane rather report a 5 fold increase in methane emission from Californian rice Paddies when compared to unfertilized soils.

C.5.5. Selection of Cultivar

Furthermore, a careful selection and breeding of cultivar is an important factor. This approach is rationalized by the fact that rice plants have been seen as one of the main routes for the transmission of methane to the atmosphere. As a recap, rice plants have a well developed aerenchymal system. So, methane produced in the soil by methanogens enters the roots of rice plants and moves by diffusion in the aerenchymal before being transmitted to the atmosphere. Therefore, a mitigation measure to reduce methane emissions to the atmosphere would be to cultivate rice varieties that do not have well developed aerenchymal systems (Wassmann *et al.*, 1993; Zou *et al.*, 2005). This is because rice cultivars vary in their exudation of organic carbon and likewise their support of methanogenesis (Bloom and Swisher, 2010).

C.6. CONCLUSIONS

As the world population continues to rise, the need for more rice cultivation will keep rising. During the wet season, Paddy rice fields tend to produce more methane while at the same time experiencing reductions in rice output. The activities of MPB go a long way to set the stage for methanogenesis. Several mechanisms have been developed to reduce methane emissions such as water management, cultivar selection, soil additives and soil amendments. Whatever the case, most of these methods are 90% efficient but have a 10% uncertainty. This study therefore recommends that a synergetic approach in which a combination of these techniques is used will yield better results.

C.7. ACKNOWLEDGEMENT

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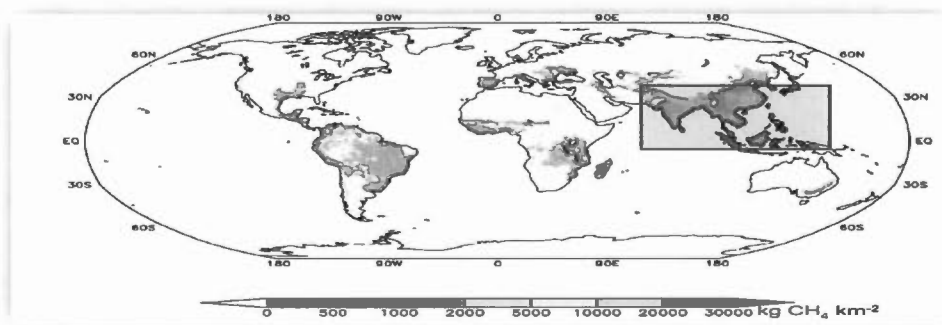


Figure C.1. Global estimates of annual methane emission from global rice Paddies at Spatial resolution of 5 minutes. Showing South East Asia in the rectangle as the contributor of about 90% of global methane from rice cultivation.

Source: Modified from Yan *et al*, (2009).

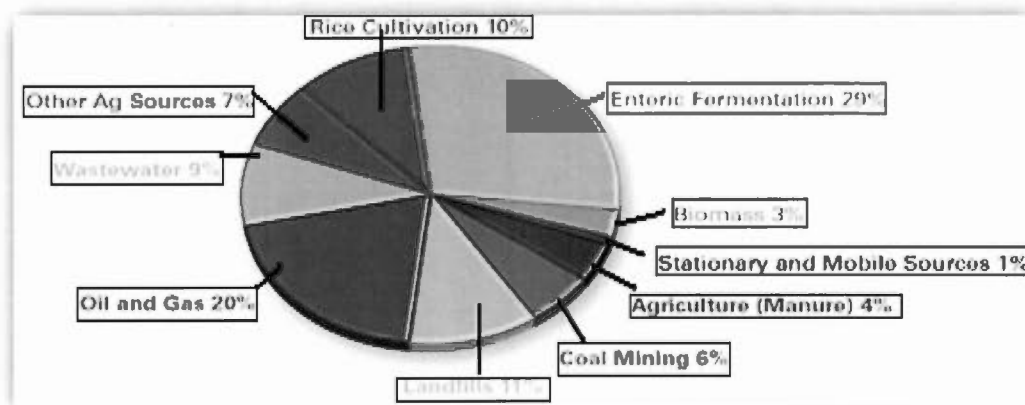


Figure C.2. Global Anthropogenic methane emission by source.

Source: Modified from Global methane Initiative, (2010).

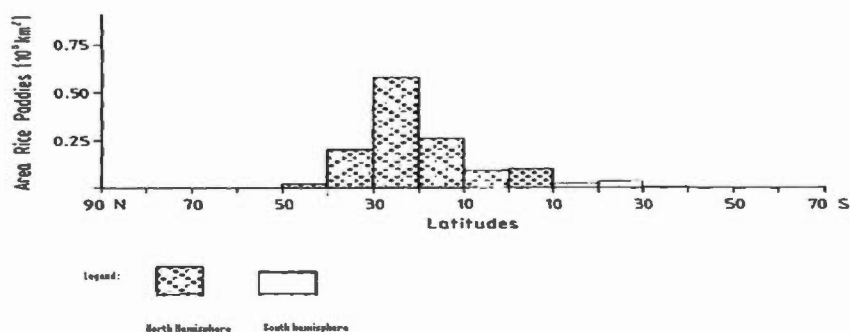


Figure C.3. Distribution of rice Paddies with latitude.

Source: Modified from Aselmann and Crutzen, (1989).



Figure C.4. Mechanisms of Methane emissions from Paddy rice field in Japan

Source: Modified from Nagata, (2010).

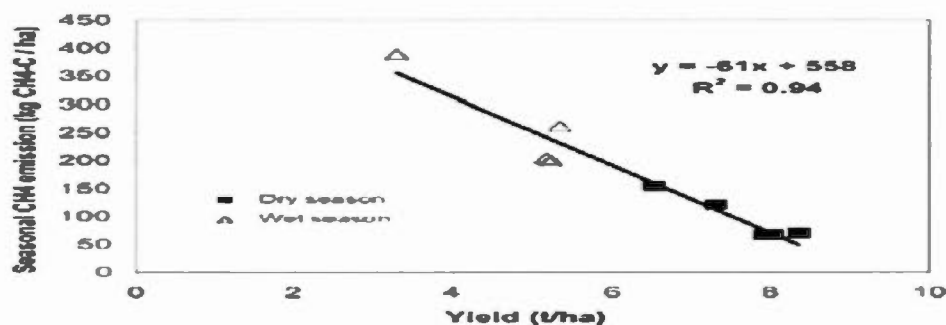


Figure C.5. Seasonal methane emission as a function of grain output in Maligaya, Philippines that shows the seasonal variations in methane emissions and grain output. The black squares represent the dry season while the triangles represent the wet season. As seen on the graph, when methane emission (y axis) is highest (350 CH₄-C per hectare), the yields are low at about 3.7 (tons per hectare). This also corresponds with the triangles which means this is during the wet season. On the other hand, we observe that when methane emissions are lowest (50 CH₄-C per hectare-t/ha) there is a higher response in output (8t/ha). This also corresponds to the black squares which represent the dry season.

Source: Modified from Denier van der Gon *et al.*, (2002).

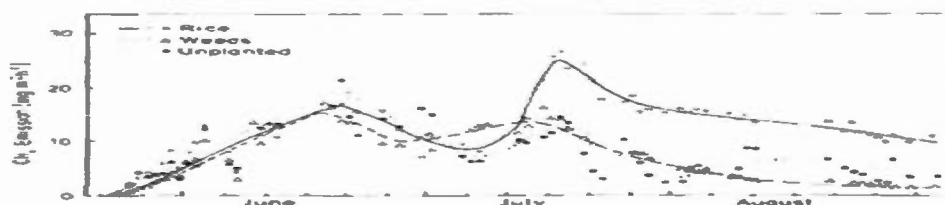


Figure C.6. Seasonal change in methane emissions from rice fields, Weeds Field and Unplanted fields.

As seen on the Figure above, the solid lines represent emissions from rice fields, the dotted lines with diamonds represent emissions from weed fields and the purely dotted lines represent emissions from unplanted fields. The data points are daily mean values of 8 individual determinations by flux measurements in 3 hours rhythm. The emissions were recorded in May 22 and the fields were flooded on May 3 and

planted on May 5. As seen on the graph, the solid lines end up dominating the entire methane emissions picture thus supporting the statement that Paddy rice field produce more methane under flooded conditions.

Source: Modified from Pschorn, *et al.*, (1986) and Nagata, (2010).

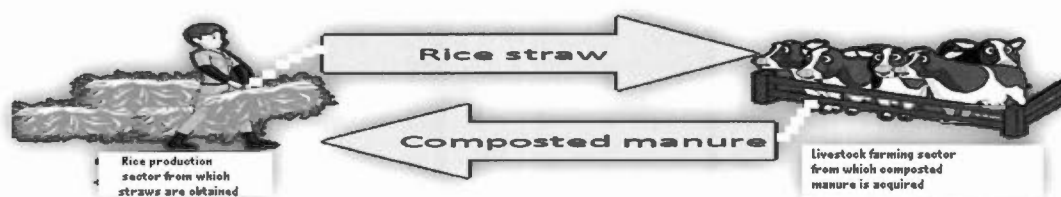


Figure C.7. Exchange of rice straw and composted manure.

Source: Modified from Nagata, (2010).