Master's Thesis in Sustainable Development

Universiteit Utrecht

ANF

Adaptation strategies for smallholder communities in the Dry Corridor of Nicaragua

An exploration on the climate change vulnerability of smallholder communities and their response towards the implementation of adaptation strategies

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Track: Environmental Change and Ecosystems
Thesis credits: 30 ECTS

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Picture source: ANF, 2018.

Abstract

Adaptation to climate change deserves specific attention for the future of rural development of Nicaragua. The smallholder communities located in the Dry Corridor of Nicaragua lack the resources and capabilities to cope with climate change (Bouroncle et al. 2016). Therefore, stronger efforts have to be made towards the implementation of site-specific adaptation strategies. This research proposes a combined approach which allows recognizing the feasibility of adaptation measures at the community level, taking into account the complexity of the climate-farming system interactions. A participatory approach is merged with a multi-criteria analysis and a quantitative vulnerability analysis. Structured and key informant interviews generate information about the climate change perception of the smallholders, their response and the difficulties they face. The results show that the smallholder communities present significant homogeneity in terms of self-organization, self-consumption and agricultural production. The vulnerability analysis displays positive values for every variable and the highest scores for the categories of water resources (1.54), forest (1.42) and livestock (1.99). Two main barriers against the implementation of adaptation strategies emerge: economic barrier and lack of knowledge. The most feasible adaptation strategies are biointensive agriculture and education. These two measures fulfil the broadest spectrum of criteria, operate on a different time-scale and allow overcoming the identified barriers. The findings suggest that future research has to move towards the development of a more holistic approach which recognizes the multi-faceted nature of agricultural adaptation in smallholder communities.

Acknowledgments

The value this entire research holds for my personal growth can be hardly enclosed in this academic report. Knowledge, interest and passion exponentially grew along with the research development and my involvement in the Nicaraguan culture. I have to express my gratitude to the entire staff of the ANF's department of Agriculture and Rural Development for their kindness and availability which exceeded any possible expectations. I thank K. Poe, the main supervisor of my project and strong inspiration for my future career. I thank my colleague B. M. Rivas, keeper of wisdom and honesty, for his contagious smile and his endless support. I thank my supervisor and my second reader for giving me the chance to undertake this project and providing constructive feedback. I thank my family, the safest nest during the difficult moments. Finally, I am grateful for the memories I collected during this Master's degree. Sharing this life-changing experience with Alex, Carlijn, Jack, Lisa, Moritz and Thijs made the last two years the most intense and valuable period of my life.

Preface

The host organization and main supporter of this research was the American Nicaraguan Foundation, founded in 1992 as a non-profit organization (ANF, 2018). The main reason for its creation was the reduction of poverty in Nicaragua through a direct contribution to the fields of food security, education and health (ANF, 2018). Its holistic approach to such a complex issue like poverty brought ANF to be one of the leading development non-profit organizations in Nicaragua (Charity Navigator, 2018). In the agriculture sector, ANF offers assistance and training to smallholder farmers, sustaining their economic stability and the achievement of food security (ANF report, 2013). One of the most relevant project is the Certified Bean Seed Project, a program intended to strengthen the entire production cycle of beans (ANF report, 2013). Through the implementation of training sessions, supplies and practical support, the small farmers participating in the project have been able to strongly increase their yearly income (ANF report, 2013). A recently conceived plan for the development of adaptation strategies in smallholder communities began together with the start of the author's collaboration with ANF. The idea is to offer four days long workshops to a selected group of small producers active in the Dry Corridor of Nicaragua focusing on agriculture innovation and the themes of climate change adaptation and vulnerability.

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Acronyms and Abbreviations

ANF	American Nicaraguan Foundation
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
CEA	Centro de Entrenamiento Agrícola
CGIAR	Consultative Group for International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
GDP	Gross Domestic Product
GHG	Greenhouse Gas
INGO	International Non-Governmental Organization
INIDE	Instituto Nacional de Información de Desarrollo de Nicaragua
IPCC	Intergovernmental Panel on Climate Change
MCA	Multi-Criteria Analysis
NGO	Non-Governmental Organization
PDSI	Palmer Drought Severity Index
PRA	Participatory Rural Approach
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar

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Introduction

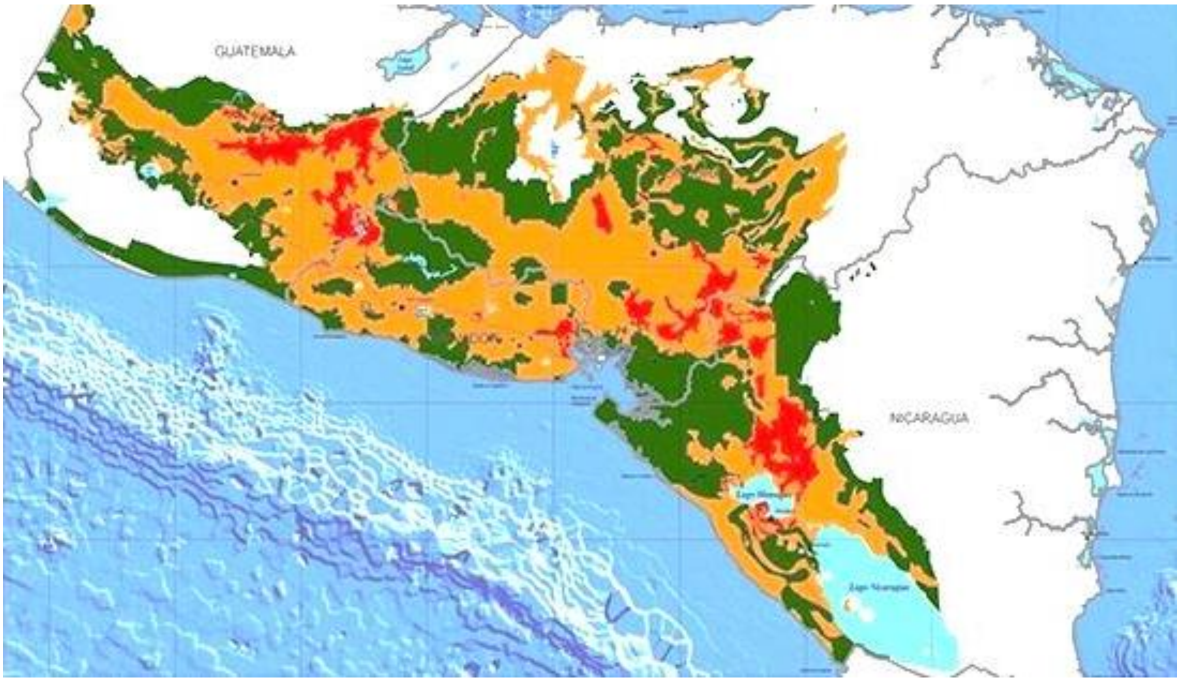
Agriculture is inherently sensitive to climate variability and is the most vulnerable sector to the impacts of climate change in Central America (Baca et al. 2011). Adaptation represents a key element of any policy response to climate change, in particular where agricultural communities are highly vulnerable to climate change (Smit & Skinner, 2002). In the case of smallholder communities, effective adaptation strategies have to be designed in locus, according to the environmental and social circumstances in which the climate stimuli are occurring (Smit & Skinner, 2002). Focusing on the smallholder communities situated in the Dry Corridor of Nicaragua[a], this research addresses the feasibility of the adaptation strategies for agriculture proposed by ANF (American Nicaraguan Foundation). The combination of a participatory approach with a quantitative vulnerability analysis and a multi-criteria analysis allows identifying the most feasible site-specific adaptation options. Scientific literature lacks a solid understanding of the connection between the local dynamics of the rural communities and the broader picture of climate change impacts on agriculture (Eitzinger et al. 2012). Research often focuses on the response of farming systems under different climate scenarios while neglecting farmers' involvement (Eitzinger et al. 2012). Thus, bringing together the human and the environmental elements of the smallholder communities, this research aims to answer the following research question:

Which climate change adaptation strategies represent feasible solutions for smallholder communities in the Dry Corridor of Nicaragua?

Climate change refers to the observed changes in the statistical distribution of global and regional climatic patterns believed to be related to anthropogenic activities (Allen et al. 2014). Between 1880 and 2012, the global average combined ocean and land temperature increased of 0.85°C (Pachauri et al. 2014). As a consequence of global warming, sea level rise, ice sheets melting and changes in extreme weather events have been observed (Pachauri et al. 2014). Future climate changes are described in the four Representative Concentration Pathways adopted by the IPCC, which show an increase of the global mean surface temperature in the range of 1.0°C to 2.0°C for 2046-2065 and of 1.0°C to 3.7°C for 2081-2100 (Allen et al. 2014). IPCC also presented in its fourth assessment report the regional climate change projections for Central America (Solomon et al. 2007). The region's annual mean warming between 1980-1999 and 2080-2099 is expected to increase in the range of 1.8°C to 5.0°C, depending on the model considered (Solomon et al. 2007). Moreover, the reduction of median annual precipitation is predicted to be between -48% and +9% by the end of the 21st century (Solomon et al. 2007). On the other hand, Solomon et al. (2007) claim that scarce research is available for Central America regarding the projections on extreme weather event changes.

[a] = the term Dry Corridor, inspired by the climatic phenomenon of El Niño, refers mainly to the ecological aggregation of similar ecosystems combined under the macro area of the tropical forest of Central America (Van der Zee Arias et al. 2012). With an extension of 39000 km^2, the Dry Corridor of Nicaragua represents more than 30% of the total area of the country (Murphy et al. 1995).

The Palmer Drought Severity Index (PDSI)[b], standardized index calculated through a physical water balanced model which combines temperature and precipitation datasets, captures the impacts of climate change on drought intensity in the Dry Corridor (Fig.1). IPCC's projections on temperature rise in Central America have been confirmed by Karmalkar et al. (2011), showing a warming of the wet season mean temperature of 4°C and of the dry season of 3°C by the end of 2100. Projections on Nicaragua's climatic trends are in line with IPCC's scenarios: temperature is expected to increase by 3.7°C (Pacific side) and 3.3°C (Caribbean side) by 2100, average annual precipitation to decrease by 36.6% (Pacific side) and 35.7% (Caribbean side) by 2100 and cloudiness to be reduced by 17.2% by 2100 (Magrin, 2007). Moreover, Nicaragua will experience a lengthening of the dry season (Ramírez et al. 2010).



PDSI level:

- **Low**: precipitation annual mean higher than 1600 mm/year, dry season length between 4 and 6 months, evaporation monthly mean lower than 100 mm/month.
- **Intermediate**: precipitation annual mean between 1200 mm/year and 1600 mm/year, dry season length between 4 and 6 months, evaporation monthly mean around 120-140 mm/month.
- **High**: precipitation annual mean lower than 1200 mm/year, dry season longer than 6 months, evaporation monthly mean higher than 200 mm/month.

Figure 1: Palmer Drought Severity Index in the Dry Corridor area, calculated with a physical water balanced model which combines temperature and precipitation datasets. Updated at January 2012. In the table the meaning of the three different level of severity. Source: Bendaña (2012), Van der Zee Arias et al. (2012).

[b] : The PDSI is a method for evaluating the intensity of a drought as a numerical quantification time- and space-specific (Palmer, 1965). It is based upon a water balanced model of which the basic input is the difference between the amount of precipitation required to retain a normal water-balance level and the amount of actual precipitation (Wells et al. 2004). A PDSI allows for practical comparison of different geographical areas (Wells et al. 2004).

The impacts of climate change on agriculture are expected to negatively influence the crop productivity, the quality and abundance of natural resources and consequently the livelihood of rural families (Nelson et al. 2009). In Central America, climate change represents a threat for food security both in terms of availability and access, with an accentuation for risk-prone self-reliant communities (Schmidhuber & Tubiello, 2007). In fact, as weather variability is the major determinant of crop productivity in underdeveloped agricultural systems, climate change is meant to jeopardize the livelihoods of many of these communities (Challinor et al. 2003). Eitzinger et al. (2012) and Bouroncle et al. (2016) show how the main crops distributed along the Dry Corridor will face severe yield losses and that the crop production needs to be shifted towards more suitable areas. In Nicaragua, it is expected that the cultivations of maize and beans will suffer a loss of respectively 33950t and 8895t between 2010 and 2020 (Hagan, 2012). In the country, the agricultural sector played a key role in the economic growth of the country after the Sandinista revolution of 1972-1979 and still represents a large piece of the actual economy, responsible of 3979.8 million US$ of the GDP in 2014 (BCN, 2014). Nevertheless, the level of agricultural development is decisively low compared to the other Central American countries both in terms of technology and crop varieties improvement (Bendaña, 2012). Smallholder communities still rely on traditional agricultural techniques, show low education level and suffer malnutrition and health-related issues (Bendaña, 2012). Traditional agriculture is also believed to be the main cause behind land degradation, environmental pollution and deforestation (Salmerón & Valverde, 2016). More useful data on Nicaragua and its agricultural production can be found in the following table (Fig. 2).

Annual crops area	500214.8 ha
Permanent crops area	316482.5 ha
Pasture area	677884.7 ha
Forested area	622574.9 ha
Protected area	2242020.0 ha
Population	6.22 million
Rural population	2.52 million
Rural population below the poverty level	1.72 million
GDP	13.23 billion US$
GDP growth	4.69%
Basic grains annual production per person	183 kg / p / year
Self-employed workers in agriculture	67.3% of the working population

Figure 2: Nicaragua's main characteristics and agricultural system. Source: World Bank (2018), Vidiani (2018), Van der Zee Arias et al. (2012).

Many studies confirm how climate change is severely threatening agriculture in Central America and how adaptation should be a priority for the future strategies of rural development (Bouroncle et al. 2014). Smallholder communities lack the necessary resources to compete with climate change challenges, including rainfall failure, temperature increase and more frequent extreme events (Choptiany et al. 2015). The complexity of the problem has been adequately discussed by Beddington et al. (2012), who address the impacts of environmental and non-environmental factors on food security. In developing countries, climate change becomes an additional burden to the pre-existing issues of poverty, inefficient governance, conflicts, economic dependency on other countries and social instability (Beddington et al. 2012). Hence, the urgency to design effective local adaptation measure for agriculture in Central America is hindered by a constellation of factors (Conde et al. 2006).

Adaptation policies have rarely been constructed in an equitable way which takes into account the farmer needs and capabilities (Mertz et al. 2009). Research on Central American agriculture and adaptation opt for model-based approaches which tend to offer solutions in isolation from the context (Conde et al. 2006). Farmer-centred approaches have to be on top of the agenda of future adaptation policies as their role can be critical in shaping the future of climate vulnerable farming systems (Fischer et al. 2002). Accordingly, CGIAR (Consultative Group for International Agricultural Research) claims that a successful initiative for climate adaptive rural development should include the design of strategies aimed at supporting poor rural families and enhancing food security while promoting the shift towards a sustainable agriculture (Nelson et al. 2009). Nicaragua has to progress towards the implementation of site-specific adaptation strategies which can enhance the ability of smallholder communities to cope with climate change challenges (Baca et al. 2011). Thus, this research attempts to propose a combined approach which might represent the first step for the development of an innovative strategy for the identification of feasible adaptation measures. In fact, it encompasses quantitative and qualitative analysis and promotes the engagement with the communities. Moreover, the research's findings are meant to be shared within the smallholders as a way to foster interest around the climate change discourse.

The structure of this report closely follows the lines of the research development. First, the theoretical background which supports this study is introduced and the main concepts and theories on smallholder communities, vulnerability and adaptation are critically explained. The conceptual design chapter clarifies how this research intends to contribute to the existent scientific knowledge. It presents the case study context, the research aim and relevance and the sub-questions. The methodology chapter describes the steps carried out in this research and the different approaches applied. The findings are presented in the results chapter, organized per sub-questions. Finally, the discussion puts the results into perspective, discussing strengths, limitations and suggestions for further research.

Theoretical background

The following chapter identifies the scientific literature on which this research is grounded. The main concepts and theories are introduced and critically explained. In particular, the theoretical background verges on the topics of climate change impacts on agriculture, vulnerability to climate change, the characteristics of the smallholder communities and adaptation in agriculture. Desk research has been conducted a priori and during the data collection.

Climate change impacts on agriculture in Nicaragua

The urgency of implementing adaptation strategies in the Central American countries is grounded on model-based research which indicates how the crop suitability of this region will drastically change in the coming years. Two recent studies have been the pillars of the development of this research.

The first one is the project "Tortillas on the Roaster", conducted by the International Centre for Tropical Agriculture (CIAT). The following text is based on Eitzinger et al. (2012). The project intended to provide useful recommendations about climate change impacts on maize and bean production in Central America in order to support decision-makers. The research formulates an analysis of site-specific climate change impacts combining primary field data with global models downscaling. The most interesting features regard the use of different software for the individuation of hot-spots for potential adaptation scenarios. It resulted that the areas where bean and maize production will no longer be possible are located in the Dry Corridor of Central America. The study specifically individuates the need of diversifying farmers livelihood in Nicaragua in the department Carazo, Diriamba and La Conquista, department Granada, Diriomo and Dirisz, and department Rivas, Belén and Potosí, and of shifting production areas in the most climate-exposed parts of the country. The different areas are classified according to the following division: Hot-spots, where future yield loss is expected between the 25% and 50% of the current yield; Adaptation-spots, where adaptation can result in creating new favourable areas; Pressure-spots, where the planting season will shift (Fig.3). Moreover, the study provides some interesting insights regarding the implementation of adaptation strategies in the agricultural system. In particular, the need for crop migration is described as a shift from the Primera[c] to the Apante[c] areas, where the suitability for the main crops production is supposed to increase.

[c] = in Central America, the three planting seasons are identified as: Primera (end of May to beginning of August), Postrera (end of September to end of December) and Apante (end of December to end of March) (Eitzinger et al. 2012).

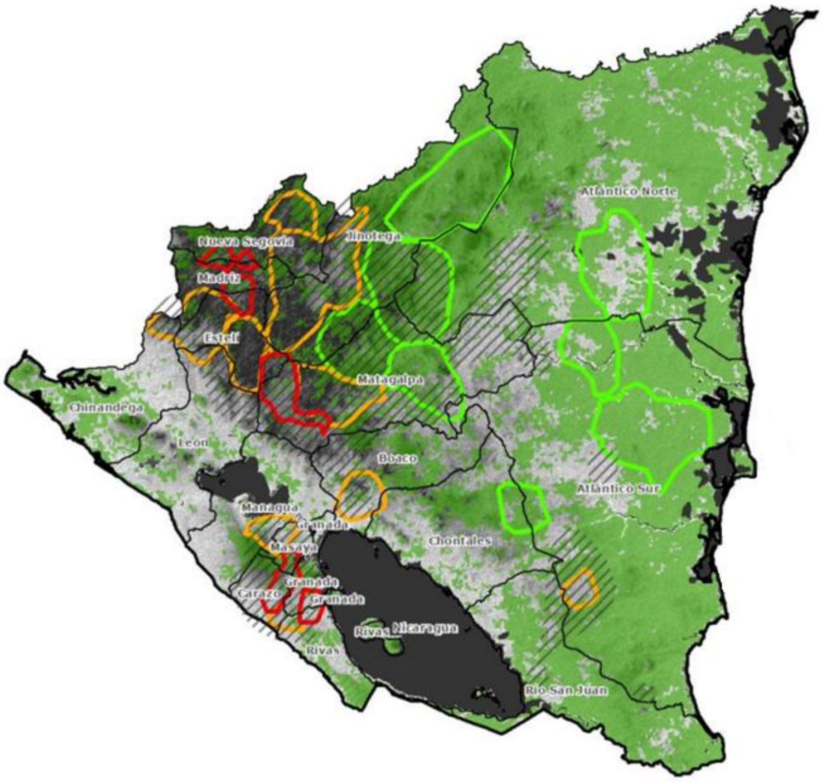


Figure 3: Hot-spot (in red), Adaptation-spot (in yellow) and Pressure-spot (in green) in Nicaragua. Source: Eitzinger et al. (2012).

The second study is the climate change vulnerability assessment carried out by Bouroncle et al. (2016). The following text is based on Bouroncle et al. (2016). The study addresses the variation in the major crops suitability in Central America, within a municipality scale (Fig.4). It proposes a useful quantitative indicator-based vulnerability assessment which takes into account the combination of cash and subsistence crops for small and medium farmers. Hence, the study enlarges the focus including the crop production for their commercial value rather than self-consumption alone. The crop modelling has been assessed in a similar but simpler way compared to Eitzinger et al. (2012). In fact, the change in climatic suitability for crops is calculated as the difference between the projected and the current one, hence without considering the growth and development of the crop throughout the years due to climate change, as Eitzinger et al. (2012) do. Adaptive capacity at the municipality level is estimated to be lower in the areas distant from big urban settlements and where the agricultural system is mainly concentrated on subsistence crops. Strengthening the findings of Eitzinger et al. (2012), the study shows how the most sensitive and risk-prone areas are situated along the Dry Corridor of Nicaragua.

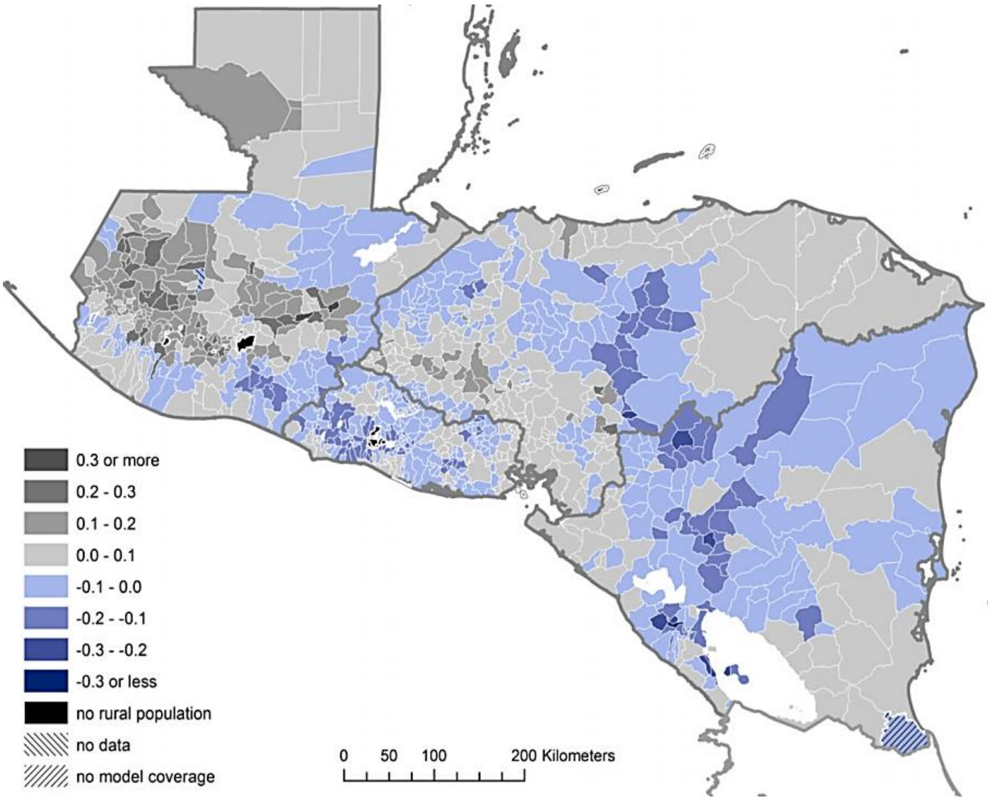


Figure 4: Average change in suitable areas for the combination of the major crops for 2030 in municipalities in Guatemala, Honduras, El Salvador and Nicaragua. Source: Borouncle et al. (2016).

Vulnerability to climate change

Climate change vulnerability assessments are performed with different intents: to understand the response of a climate-sensitive system under changing conditions, to analyse the target of climate change policies, to prioritize research efforts within a climate-sensitive sector and to help the development of adaptation strategies (Fussel & Klein, 2006). Considering that each of these purposes deserves a peculiar attention, the evolution of vulnerability assessment evolved in different directions (Fussel & Klein, 2006). Different emphasis has been given to the aspects of stakeholder engagement, population response, climate change scenarios and environmental policies (McCarthy et al. 2001). This research implemented a vulnerability analysis as a mean to understand the climate change response of smallholder communities and to support the future interventions ANF will realise. In fact, assessing vulnerability to analyse the capacity of a system to react to external stress can contribute to improving future adaptive intervention on the system (Kelly & Adger, 2000).

The many existing definitions and the common use of the term vulnerability generated a lot of confusion around this concept. It generally refers to the relation between climate change impacts and how the influenced target cope with it (Hufschmidt, 2011). In this research the IPCC's definition of vulnerability has been adopted: "Vulnerability regards the propensity or predisposition to be adversely affected. It encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014). Vulnerability is the result of the combination of three different elements: exposure, sensitivity and adaptive capacity (IPCC, 2014). Their definitions are adopted from Ortega & Paz (2014):

- Exposure: presence of people, livelihood, infrastructure, ecosystems, environmental resources and economic, social or cultural assets which can suffer the impacts of climate change because of their geographical position.
- Sensitivity: degree to which a system is affected by or responsive to climatic variations.
- Adaptive capacity: potential of a system to adapt or alter itself as a response to climatic variations.

Hence, vulnerability is a function of the exposition of a certain system to climate stimuli and its capacity to adapt to the effects provoked by climate stimuli. The interconnection between the concepts introduced is shown in the following scheme, adapted from Marshall et al. (2010) (Fig. 5). It can be seen how exposure and sensitivity together represent the total impact of climate change on the system in the case that no adaptation measures are taken.

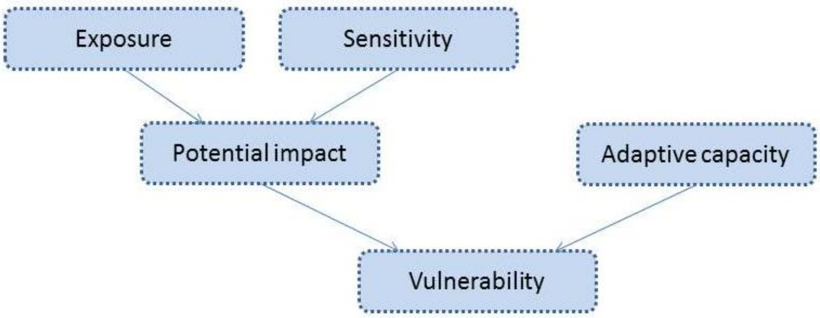


Figure 5: Concepts of vulnerability and their relations. Source: author's own on the base of Marhsall et al. (2010).

Smallholder communities

Central American countries have relied on agriculture as the main driver of their economies since the beginning of the last century (Bouroncle et al. 2014). In Nicaragua, agriculture represents the first source of employment in the rural areas of the country and two-thirds of the overall income of the poorest part of the population (WorldBank, 2018). Despite the value it holds, agriculture did not achieve a sufficient level of development to guarantee support in terms of food security and economic benefits for the Nicaraguan population (ANF, 2018). In fact, although the overall poverty trend has decreased since 2005, the 50.1% of the total population still remains below the poverty level (INIDE, 2015). One of the main limitations for the development of a stronger and more resilient agriculture relies on the persistence of the traditional organizations recognized as smallholder communities (Altieri & Koohafkan, 2008).

Although it is arduous to find an exact definition of smallholder community, certain characteristics are widely recognized to be recurring. Chai͡anov (1986) defines some of the key features of the concept as the reliance on family labour, self-organization, self-consumption and non-existent or small exports. Despite the usual small dimension of smallholder farms, including the farm area in the definition might be more confusing than convenient (Berdegué & Fuentealba , 2011). Another equally important characteristic is the weak economic performance of the farms as a consequence of their dependency on different environmental, social and economic factors (Berdegué & Fuentealba, 2011). Altieri et al. (2012) emphasize other features: strong resilience in coping with small human and environmental disturbances; stable production of local and traditional food through traditionally nurtured agricultural systems; social self-regulation based on cultural values.

The importance of traditional farming systems is not only due to the intrinsic and historical value of agriculture as a symbol of cultural heritage (Altieri & Koohafkan, 2008). One of the other positive facets is the possible high degree of biodiversity, specifically of vegetation diversity as a result of polycultures (Altieri et al. 2012). In fact, biodiversity represents the key for species conservation, reduction of diseases risk and climate change resilience (Lavergne et al. 2010; Salkeld et al. 2013; Borrvall et al. 2000). The benefits of increased biodiversity also concern the enhancement of diet diversity and the maximization of productivity against the limited technology available (Altieri & Koohafkan, 2008). Smallholder communities are also believed to be the keepers of social and human capitals through the reinforcement of groups cohesiveness, communities networking, individuals status and local knowledge (Altieri & Koohafkan, 2008). From an economic point of view, smallholders can have a high potential to integrate themselves into the market if they are able to use community collaboration as a leverage to decrease labour costs (Marshall et al. 2006).

On the other hand, smallholder communities have been defined as severely risk-inclined (Pacey & Thrupp, 1989). Many limitations derive from their dimensions. In fact, the local condensation of agriculture reveals an evident dependency on land characteristics like soil condition, water and resources availability (Morton, 2007). Other stressors are community population increase, market pressure, external policies and conflicts with other communities (Morton, 2007). In general terms, it can be said that smallholder communities can flourish in rather static than dynamic environments, as their strengths are maximized where the context in which they develop is not likely to be changed (Choptiany et al. 2015). In fact, the interactions with the wider agriculture market are not sufficiently articulated in order to guarantee the technological and economic inputs to take part in the smallholder system development (Collinson, 2000).

Adaptation strategies for the rural development of Nicaragua

Following the lines of the United Nations Framework Convention on Climate Change, adaptation strategies are considered a response to climate change which aims to reduce the vulnerability of social and biological systems, reducing or even compensating the climate change impacts (UNFCCC, 2010). The definition of adaptation strategy adopted in this study was formulated by IPCC as: "adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" (IPCC, 2014).

Frequently, a greater focus has been given to mitigation rather than adaptation, both from a policy and from a scientific prospect (Fussel & Klein, 2006). Mitigation efforts comprehend all human activities which limit the magnitude of long-term climate change, contributing for instance to the reduction of GHG emissions or to the storage of carbon dioxide (Metz et al. 2007). Focusing on mitigation prevailed because of the possibility to theoretically reduce all impacts on climate-sensitive targets (Verchot et al. 2007). GHG reduction or storage can be easily monitored, favouring the quantification of the avoided climate change impacts and the creation of mitigation policies (Fussel & Klein, 2006). In general terms, if mitigation aims to avoid what can be still avoided, adaptation focuses on the management of adverse situations. Despite its apparent unpopularity, adaptation started prevailing at the local level, where the reality of climate change impacts is tangible (Reid & Huq, 2007). Many arguments are in favour of local adaptation. The GHG emissions of the last decades together with the inertia of the Earth's climate system revealed that many of the planet's environmental boundaries have been overshot and to a certain extent climate change cannot be avoided (Fussel & Klein, 2006). Additionally, while the effect of mitigation measures will be experienced in a long-term perspective, adaptation can offer immediate benefits (Fussel & Klein, 2006). Lastly, many adaptation strategies can be better implemented on the small scale, supported by localized economic interventions and people participation (Fussel & Klein, 2006). Cartwright et al. (2013) show how adaptation can be successful in the local context as it generates economic benefits next to the environmental ones. Hence, adaptation strategies are believed to be of major relevance in the context of smallholder communities (Wright et al. 2014). The scale, the scarcity of resources, the weak economy and the scarce predisposition to cope with environmental disturbances suggest the importance of integrating community-based initiatives in large-scale adaptation programmes (Wright et al. 2014). Local adaptation also represents a double opportunity to cope with climate challenges while fostering a process of social learning (Collins & Ison, 2009).

Ravera et al. (2011) stated that the scarce success of agricultural adaptation in Nicaragua is related with the farmers' tendency to maintain a traditional grain system. At the same time, the attempts made towards agriculture intensification only resulted in increased soil erosion and increased dependency on fertilizers and pesticides (Ravera et al. 2011). Deforestation and agricultural expansion have been often considered a response to cope with agricultural losses (Tarrasón et al. 2010). In fact, Nicaragua's tropical forest has been heavily affected by intensive deforestation in terms of both species composition and forest structure (Tarrasón et al. 2010). Adaption through technological innovation has been prevented by the unequal distribution of wealth which weakened farmers' ability to cope with climate change (Ravnborg, 2008). The economic limitation in the adoption of new technologies in Nicaragua has been intended by Mendoza et al. (2012) as the most urgent issue to be faced in order to guarantee the development of adaptation strategies. Practices including efficient water management, crop varieties improvement, forecasting and insurance all belong to a category of adaptation strategies which are not feasible in a poor local context because of the level of initial or constant investment needed (Lybbert & Sumner, 2010).

Positive results with already implemented adaptation strategies in smallholder agricultural system come from a range of practices which focus on the use of local resources and do not require excessive investment and maintenance (Mendelsohn & Seo, 2007). Local adaptation needs to be shaped accordingly with the environmental and social characteristics of the local context, envisioning adaptation actions as measures which engage with and involve the farmers (Mendelsohn & Seo, 2007). Hence, adaptation becomes the result of individual decisions influenced by either external or internal factors (Smit & Skinner, 2002). Smit & Skinner (2002) include in locally feasible adaptation strategies farm production practices like diversifying crop types and varieties, changing production techniques, changing the location of crops, implementing simple irrigation systems and shifting the time of agricultural operations. Agroforestry is also believed to be a strategy which can positively contribute in social, economic and environmental indicators while presenting an effective measure for coping with droughts and unusual rain events (Villanueva et al. 2009). Smithers & Blay-Palmer (2001) individuated the main technology-based adaptation strategies in the small-scale dimension as irrigation, water harvesting and zero soil tillage. Structural methods which do not require excessive investment can also be a valid option to face soil degradation, like stone bunding and terracing (Shiferaw et al. 2009). To conclude, adaptation strategies in smallholder farming system should focus on a farmer-centered approach which establishes inclusion, involvement and empowerment of the farmer while capitalizing on local resources.

Barriers and drivers for adaptation strategies

Adaptation strategies know many barriers and drivers that control their applicability and effectiveness. Moser & Ekstrom (2010) identify barriers throughout the main phases of the adaptation process, in order to create the basis for a successful implementation of adaptation strategies. Within the context of smallholder communities, many of the barriers are definitely relevant. Information accessibility, credibility and speed of response are crucial to convince the target actors of the necessity and urgency of a certain strategy (Moser & Ekstrom, 2010). In the development of the adaptation strategy, the lack of constant communication and participation during the ongoing implementation process as well as the lack of control from an established leading authority are others underlying barriers (Moser & Ekstrom, 2010). Finally, it is important that the outcomes positively hit to the greater extent the intended target of the strategy through tangible benefits, in order to foster credibility and confidence for the implementation of other projects in the future (Moser & Ekstrom, 2010).

Focusing on social barriers, Adger et al. (2009) define different assumptions to describe social drivers which might intervene in climate change adaptation. In particular, they state that adaptation finds its limits within the ethical and the cultural spheres (Adger et al. 2009). In fact, the understanding of risk and consequently the perceived urgency of a strategy change over time in line with values and mentality change (Toman, 2006). Actions are outlined by societal and cultural norms, intrinsically malleable because subjectively constructed (Adger et al. 2009). Social barriers are rooted in individual values, especially when it comes to the small community dimension (Adger et al. 2009). The last assumption discussed by Adger et al. (2009) deserves particular attention: the value of the forced loss of places. As Turner argues (2008), when a certain strategy implies the forced migration of the people affected, a strong resistance rises from the emotional and traditional attachment to the land. The perception of climate change can also shape the farmer response. Wolf & Moser (2011) describe the key role of the individual status like age, gender, social position and wealth. Although it is difficult to quantify to what extent these social variables influence the individual's judgment on climate change, the evidence shows that they have to be taken into account (Wolf & Moser, 2011). In particular, it appears that climate change perception is shaped by beliefs detained by individuals regarding nature functioning, fairness and even religion (Wolf & Moser, 2011).

Other constraints on adaptation might come from inadequate education, lack of knowledge and erroneous perception of risk (Eakin & Lemos, 2006). In other words, the adaptive capacity of the individual depends on his knowledge of what adaptation is about and which benefits he can gain from it (Eakin & Lemos, 2006). Smit & Pilifosova (2003) list additional determinants which influence adaptation at the local level as technology, financial capital, material resources and wealth distribution. These barriers can be clustered under the broader aspect of the economic capital (Smit & Pilifosova, 2003). Finally, another important external barrier is represented by the institutional constraints in form of laws and regulations (Yohe & Tol, 2002). Informal and formal rules on natural resources management, risk management, property rights and bureaucratic mechanisms can interfere with the implementation of adaptation strategies (Yohe & Tol, 2002).

Identification of adaptation strategies for agriculture

A growing body of literature addresses the adaptation strategies for agriculture, their implementation and the driving factors underpinning their success. Certainly, a selection of these options is needed in order to understand which strategies are the most relevant for the smallholder communities in Nicaragua. Harvey et al. (2014), within the analysis of the synergies between adaptation and mitigation strategies in tropical areas, propose to classify possible agricultural practices within three different scales: plot, farm and landscape. The plot scale refers to the practices which focus on the crop treatments like the variety selection and breeding, the planting time shift and the irrigation techniques (Harvey et al. 2014). The farm scale encompasses the production system within a more general span: rotation, water harvesting, seasonal forecasting and diversification (Harvey et al. 2014). Finally, practices overstepping those strategies exclusively related to agricultural techniques occur at the landscape scale. In particular, diversification of farmer income, maintenance of habitats connectivity and land use planning belong to this last category (Harvey et al. 2014).

Another useful approach is the time-based selection from Vermeulen et al. (2012). Adaptation strategies for smallholders fall into two vast overlapping zones: long-term adaptation to progressive climate change and short-term adaptation for increased climate variability and extreme weather events (Vermeulen et al. 2012). Because of the high sensitivity of agriculture to climate change, adaptation strategies need to be analysed at different time scales (Vermeulen et al. 2012). As the food system has to keep the pace with growing food demand in developing countries, long-term adaptation strategies can help in facing the challenge of increasing food security (Hazell et al. 2010). On the other hand, extreme weather events create the urgency of preventing agricultural negative impacts in the short-term (Vermeulen et al. 2012). In fact, droughts, floods and heat waves represent a threat especially for smallholder communities in tropical areas (Vermeulen et al. 2012). Hence, the identification of adaptation strategies based on the time period needed for their application and functioning represents another key to develop a meaningful selection of existing adaptation strategies.

Multiple criteria are needed to understand the feasibility of adaptation strategies compared to the context they are applied in (Smit & Skinner, 2002). An interesting input comes from the findings of Vignola et al. (2015). In the presented framework, a strategy which can be applied within the smallholder context needs to meet at least one of the criteria proposed per each dimension (Vignola et al. 2015). The three dimensions are: ecosystem-basedness, adaptation benefits and livelihood security. While the first dimension is not relevant within the focus of this research, the other two dimensions describe a reliable method for the classification and selection of adaptation strategies. In fact, this framework permits to identify existing practices which can be applied in smallholder communities assessing the satisfaction of significant criteria like use of local inputs, affordable investments for smallholders, respect of traditional knowledge and reduction of extreme weather events impacts on the farming system (Vignola et al. 2015). Another set of criteria for agricultural adaptation is presented by Smit & Skinner (2002). While some of the criteria are similar to the previous study, additional ones regard the enhancement of innovation, generation of information and cost-effectiveness (Smit & Skinner, 2002). In the following table (Fig.6) the criteria for selecting adaptation strategies for agriculture extracted from Vignola et al. (2015) and Smit & Skinner (2002) are shown.

Criteria for the selection of adaptation strategies
Maintains or improves crop, animal or farm productivity in face of climate variability and climate change[1]
Reduces the biophysical impacts of extreme weather events and high temperature on crops, animals or farming system[1]
Reduces crop pest and disease hazards due to climate change[1]
Increases or diversifies income generation of smallholders[1]
Respects the local or traditional knowledge of smallholder farmers[1]
Uses locally available and renewable inputs (e.g., using local materials from within the farm or landscape, rather than external inputs such as pesticides, inorganic fertilizers, etc.) [1]
Requires implementation costs and labour affordable to smallholder farmers[1]

Develops farm-level resource management innovation to address the risk associated with climate change[2]
Fosters education and generation of climate-specific knowledge[2]
Empowers the community members[2]

Figure 6: List of the criteria for the selection of adaptation strategies for agriculture. Source: Vignola et al. (2015)[1] and Smit & Skinner (2002)[2].

Conceptual design

The following chapter wants to specify the relevance and the aim of this research. The contribution of this study to the existing scientific literature and the knowledge gap it intends to fulfil are clarified. The research aim and the six sub-questions are presented. An introductory paragraph about Nicaragua and its history serves to create a better understanding of the context where the research took place.

The Nicaraguan context

Nicaragua is an amalgam of deeply-rooted colonial traditions and indigenous cultures. It offers stunning landscapes, pristine forests and abundant fauna. Nicaragua's beauty well hides its delicate equilibrium, its weaknesses and its political and environmental instability. The history of the country is a constellation of bloody wars, leadership, political crisis and armed revolutions (Kinloch Tijerino, 2008). The Spaniards entered the country for the first time in 1522 with explorative intents, although the unavoidable clash with the indigenous populations was devastating (Herring & Herring, 1968). Since then, Nicaraguan history has remained static for about three centuries of Spanish colonization (Newson, 1992). Before arriving at the current situation, Nicaragua had to go through the American Invasion of the early 90's, the Civil War of 1926-1927, the four decades of the Somoza's dynasty and the endless Sandinista revolution of 1972-1979 (Keen & Haynes, 2012; Black, 1981). The last democratic presidency, held by the re-elected President Daniel Ortega, recently showed evident signs of instability. The ongoing civilian protest started the 19th of April 2018 demanding the ouster of the president, accused of corruption and autocracy, signifies the imminent collapse of the country's political system (La Prensa, 2018; The Guardian, 2018).

The history of Nicaragua has been equally shaped by natural events. Environmentally speaking, Nicaragua belongs to the delicate Central America and Caribbean region, making it a country prone to suffer natural disasters and climate change impacts (Charvériat, 2000). Considering that these events are not a novelty in this area, Charvériat (2000) even considers them of relevant importance for the historic and economic development of the affected countries. The country has been ranked fourth in the list of the world's most vulnerable countries to extreme natural events according to the Global Climate Risk Index (Kreft et al. 2014). Indeed, Nicaragua experienced over recent decades earthquakes, eruptions, tidal waves, tsunami and droughts (Caldera et al. 2001). A disastrous example is the hurricane Mitch of 1998, which recorded approximately 3000 fatalities, over half a million homeless and more than 1 billion $ in damages (Guha-Sapir et al. 2004). Despite the incessant effort of government, NGOs and INGOs, the recovery procedures have been slow and partially efficient, certainly inadequate to rehabilitate rural livelihoods (Van den Berg & Burger, 2008). Natural disasters have been demonstrated to have multiple adverse effects on the population's integrity. Direct consequences like death and injuries are often associated with post-traumatic psychological diseases, loss of income and loss of property (Charvériat, 2000). Unfortunately, the risks associated with extreme events have not decreased despite the numerous interventions at the national and international levels (Cohen & Werker, 2008). Instead, economic costs related to natural disasters are expected to increase as a result of the accumulation of economic assets and the persistence of poverty and technological under-development (Charvériat, 2000). The country continues to rely on post-event interventions and international economic support, unable to undertake any initiative and actively designing a plan of action (Barenstein & Leemann, 2012). Under this complex umbrella of intern instability and environmental sensitivity, it appears clear how climate change represents a serious threat for Nicaragua. A proactive approach is needed in order to focus every effort towards the creation of effective strategies which can lead Nicaragua to be actively involved in climate change adaptation.

Knowledge gap and research relevance

Central America is believed to be the tropical region where climate change impacts will hit in the most severe way (Giorgi, 2006). This evident exposure in combination with the economic reliance of Nicaragua on agriculture and its political instability generates urgency for the implementation of successful strategies to cope with climate change (Bouroncle et al. 2016). Just a few studies on Central America exist to promote adaptation strategies in agriculture and facilitate rural development. Also, the existing studies on agricultural production and the relative climate change impacts expand just to the national level or focus on community groups (Eitzinger et al. 2012). Only Bouroncle et al. (2016) went a step further through the identification of climate change vulnerability at the municipality level and the description of rural populations adaptive capacity across Nicaragua, Honduras, Guatemala and El Salvador. Eitzinger et al. (2012) call for the need of a multidimensional research approach which balances the theoretical application of adaptation strategies with the farming-environment dynamics. It is stated that including farmers experience in future research and fostering the discussion on climate change within communities are the keys to generate site-specific successful adaptation strategies (Eitzinger et al. 2012). Following the claimed limitations and suggestions for further research of the aforementioned papers, this study proposes a more precise and narrow approach. Firstly, it focuses on the community dimension rather than the municipality dimension. Moreover, it integrates social and anthropological elements to analyse the real potential implementation of adaptation strategies. The adoption of a bottom-up approach which places smallholders as the main source of information and fosters participation and involvement in the research process wants to provide an innovative perspective on the climate change response of the rural communities of Nicaragua.

Hence, this research wants to capture different insights into a scarcely studied field, digging deeper into the connections between potential adaptation strategies and the realistic implementation of them. Indeed, the hope is that complementing quantitative analysis with the investigation on the human element of the smallholder communities will promote a more conscious and tangible approach towards the issues of climate change and food security in Nicaragua. Climate change impacts are investigated from the smallholder perspective as a complementary contribution to the existing scientific literature on climate change scenarios. Moreover, the inclusion of the identification and ranking frameworks for adaptation strategies gives a more tangible character to this study. The findings of this research are also meant to be of practical use for a successful implementation of ANF's future projects.

Research aim and Research Question

This research aims to analyse the feasibility of existing adaptation strategies which may allow smallholder communities facing future climate change challenges while preserving their livelihoods. In particular, it focuses on the smallholder perception of climate change impacts on agriculture and the community vulnerability. Moreover, this research intends to individuate which barriers might impede the implementation of new adaptation strategies. Hence, the main research question is the following:

Which climate change adaptation strategies represent feasible solutions for smallholder communities in the Dry Corridor of Nicaragua?

The research question is divided into six sub-questions:

Sub-q.1:Which are the main characteristics of the smallholder communities?

Sub-q.2:How do smallholders perceive and experience climate change impacts?

Sub-q.3:Which adaptation strategies for smallholder communities have already been implemented?

Sub-q.4:Which barriers are the most influential in limiting the implementation of potential adaptation strategies?

Sub-q.5:What is the vulnerability to climate change of the smallholder communities?

Sub-q.6:Which adaptation strategies can be identified as most promising for a successful implementation in the smallholder communities?

The selection of smallholder communities

As already mentioned, the target of this research is represented by the smallholder communities located in the Dry Corridor of Nicaragua. In fact, ANF intends to address the climate change vulnerability of these communities in order to create a stronger understanding of the context in which future projects will take place. ANF has been already active in the communities for almost two years, either through localized projects or with simple networking.

The smallholders participating in this research came from the communities showed in the following map (Fig.7). From South to North, the communities are: Agua Caliente, San José de Cusmapa, Las Sabanas, El Castillito, San Lucas, La Guayaba, Uniles, Somoto, Cacauli, El Cascabel and Santa Rosa. The selection of the communities was made from ANF before the beginning of the workshops following the geographical closeness of the communities involved in ANF's interventions. The selection of the participants was also made by ANF on the base of the their availability and trying to guarantee the highest heterogeneity in terms of age and education.

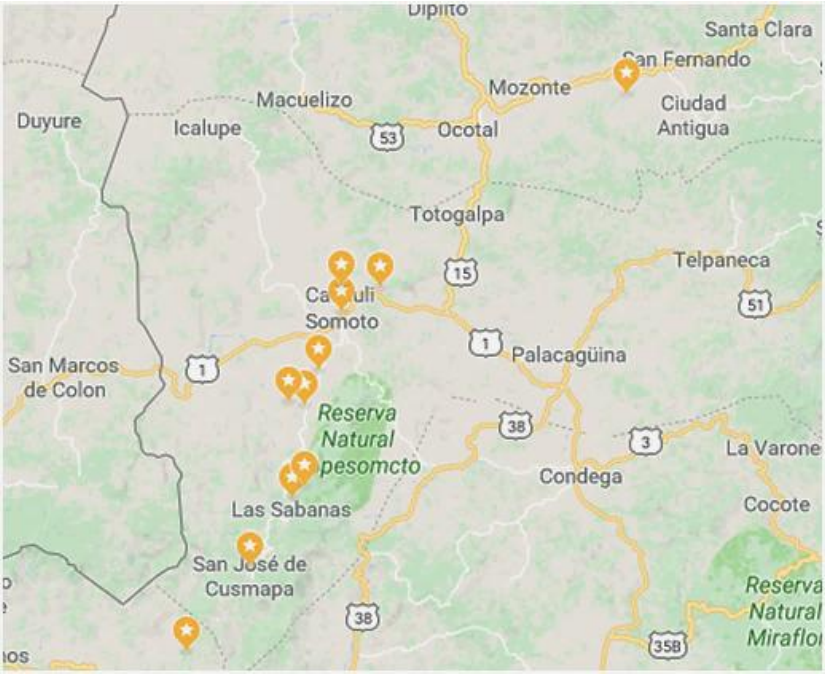


Figure 7: Geographical distribution of the communities involved in the study, indicated by a star. Source: author's own.

The workshop which will be further introduced took place in the Agriculture Training Center CEA (Cientro de Entrenamiento Agricolo), situated Est of Tipitata (Managua, Nicaragua). The center is owned and managed by ANF and used for a variety of purposes.

Methodology

The following chapter describes the methods which have been used in this research. As it can be seen in the research framework (fig.8), different methods have been implemented in order to answer the sub-questions in an adequate manner. All methods used to answer one or more sub-questions are briefly introduced:

Sub-q.1: key-informant interviews together with structured interviews with the smallholders allowed to identify the community characteristics.

Sub-q.2: structured interviews and group discussions generated information about the smallholders perception of climate change, their understanding of climate related concepts and the way they experience climate change impacts. A climatic calendar helped in the identification of the unusual climate events that smallholders have experienced.

Sub-q.3: key-informant interviews together with structured interviews with the smallholders allowed individuating the adaptation strategies already implemented in the communities.

Sub-q.4: structured interviews with the smallholders allowed identifying and ranking the perceived barriers against the implementation of adaptation strategies.

Sub-q.5: a vulnerability analysis based on the questionnaire from Ortega & Paz (2014) was conducted in order to address sensitivity, adaptive capacity and vulnerability to climate change of the communities.

Sub-q.6: an identification framework and a ranking framework were implemented to identify and classify the adaptation strategies that ANF proposes.

The interconnections among the different stages of the research are clarified in the research framework. On the left side, the implementation of workshops which has been fundamental for the data collection and for conducting the vulnerability analysis. On the central part of the framework, structured interviews and group discussions with the members of the communities have been conducted to analyse the smallholder perception of climate change impacts, the community characteristics and the main perceived barriers against the adoption of adaptation strategies. On the right side of the framework, the literature review used to analyse and classify the adaptation strategies that ANF proposes. In the box on the top-right of the framework, the key informant interviews conducted to study the context of the research and strengthen both the reliability and the righteousness of the chosen approaches. The three different approaches led to the identification of the most feasible adaptation strategies that ANF could implement. The various stages of the research are explained in the following sub-paragraphs.

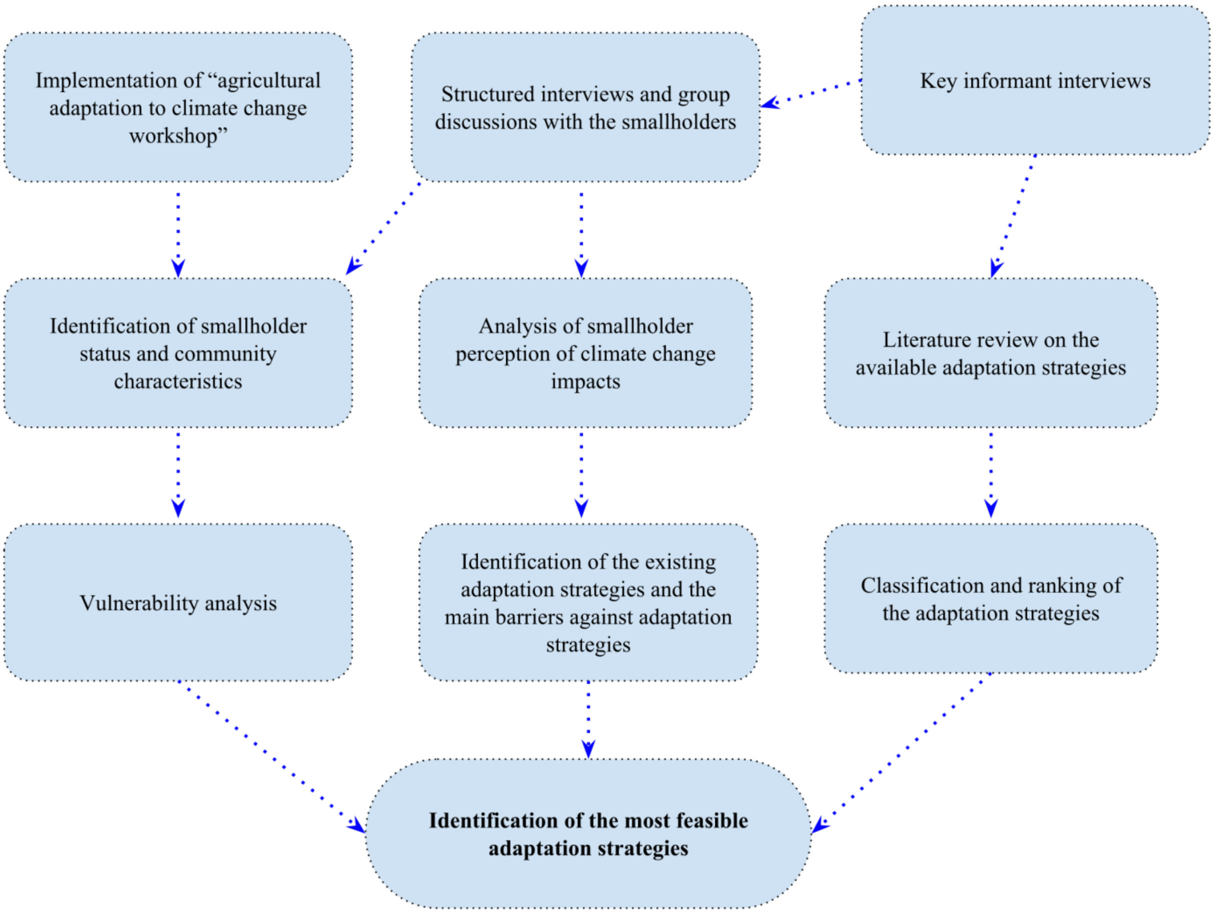


Figure 8: Research framework which explains the connection between the different methods adopted in this research. Source: author's own.

Key informant interviews

Key informant semi-structured interviews have been conducted before and after the workshops. This stage was of fundamental importance because it allowed for actual engagement with and immersion in the research context. Certain aspects that were not possible to be grasped during desk pre-investigation have been examined. Moreover, key informant experience became useful to receive a precious feedback on the author's approach and research methods, pointing out potential weaknesses and creating space for improvement.

Semi-structured interviews permit a certain degree of freedom in the data gathering process as they are more likely to grant very complete responses compared to other qualitative methods (Harrell & Bradley, 2009). Harvey-Jordan & Long (2001) underline how semi-structured interviews can create unexpectedly rich data and can be used as a tool for a mutual learning between the interviewer and the interviewed. In this study, descriptive-corrective interviews have been applied. According to McIntosh & Morse (2015), the purpose of a descriptive-corrective interview is to evaluate and interpret potential discrepancies between anticipated and actual discourses, comparing the outsider's view with the perspective of the ones who gained their knowledge from direct experience. Hence, the interviews helped to elaborate upon the assumptions formulated during desk pre-research around the spheres of climate change local impacts, the barriers against the implementation of adaptation strategies and the usefulness of the research methods.

The structure of the interviews was designed in order to focus on the investigated themes while leaving sufficient freedom for possible deviations. The open-ended nature of some of the questions allowed for the elaboration of long and detailed answers as well as the generation of discussions. The interview's structure focused on the following topics, on the same order: respondent status; career and experience; experience with ANF (if existent); current job and projects; climate change impacts on agriculture in Nicaragua; existent and possible adaptation strategies for agriculture; smallholder community characteristics and vulnerability; existent barriers against the adoption of adaptation strategies; workshop structure; suggestions for further improvement of the research. All the key informant interviews have been recorded, translated and transcribed for a correct data analysis. The key informants have been selected on the base of ANF's staff availability and the affinity between their expertise and the themes this research verged on. In particular, the main selection criterion was the direct or indirect involvement in the workshop. In the following table (Fig. 9), the key informants who have been interviewed.

Key informant	Role	Time of the interview
Berklin Martinez Rivas	Vice-responsible of the CEA and teacher at the workshops on the themes of biointensive agriculture and biodigesters	Before the workshops
Hector Alvarez	Professor in agronomy and teacher at the CEA workshops in the themes of apiculture and organic agriculture	Before the workshops
Sayra Taleno	Employee in CATIE focusing on small-scale agriculture, collaborating with ANF as the main consultant for the development of the workshop	Before the workshops
Keith Poe	Agriculture and Rural Development Manager for ANF	After the workshops
Fabiola Areas	Director of Sonati, NGO operating in Nicaragua on environmental education and nature conservation	After the workshops

Figure 9: List of key informants who have been interviewed either before or after the workshops. Source: author's own.

Participatory Rural Appraisal

The Participatory Rural Appraisal (PRA) was the fundamental approach adopted to engage with the community members. In fact, within the sphere of climate change adaptation, participatory approaches have been proved to be a strong support to many risk-reduction projects (Van Aalst et al. 2008). Bottom-up approaches like PRA ensure gathering information which can be scaled up and integrated into the formulation of adaptation policies (Rojas Blanco, 2006). Farmers' integration in the development of adaptation initiatives represents the key mechanism to link national and local levels (Wright et al. 2014). In particular, the inclusion of participative vulnerability assessments helps to tailor adaptation strategies to local contexts (Wright et al. 2014). Van Aalst et al. (2008) state that an adaptation measure occurring at the community level needs to be based on the evaluation of people's adaptive capacity. This necessity comes from the discrepancy between what an adaptation measure requires and what people are actually able to understand and accomplish (Burton & Van Aalst, 2004).

The need for a new approach which involves people and makes the social and cultural spheres the pivotal points of rural development comes from many interconnected defects characterizing conventional qualitative research (Chambers, 1997). For instance, low time efficiency, prioritizing things against people and neglecting poor and uneducated people (Chambers, 1997). Instead, PRA stresses the cost-efficiency and the quality of the data collection (McCracken et al. 1988). More attention is paid to the empowerment of people, recognizing both their role in the research development and the importance of their specific knowledge (Chambers, 1997). According to Chambers (2005) the Participatory Research Appraisal encompasses the following principles:

- Reversal of learning: the researcher learns from the participant through a direct contact with him on the site. Personal interactions allow sharing local knowledge, both social and technical.
- Rapid and progressive learning: instead of following a pre-designed scheme, the researcher needs to be flexible and adaptable throughout the entire process. Conscious exploration, improvisation, iteration and self-criticism are the keys for an effective learning approach.
- Offsetting biases: a relaxed and natural attitude is considered fundamental. The researcher should listen instead of lecturing, putting himself on the same level of the participants.
- Optimization of the trade-offs: considering the four trade-offs of quantity, relevance, accuracy and timeliness, the researcher should be able to understand which information is really worth to be collected for the goals of his study, especially considering the time and economic limitations.
- Triangulation: a stronger and more reliable information is obtained through the combination of different methods, approaches and disciplines.
- Seeking diversity: the diversity and richness of information are considered more significant than looking for averages.
- Facilitation: the researcher should facilitate the investigation by guiding the participant to understand both the process and the outcomes of the research.

- Self-critical awareness and responsibility: the researcher has to constantly examine the ongoing process and his own behaviour. Being aware and embracing mistakes can create opportunities for improvement.
- Shared information and ideas: information about the research process and the data collected has to be shared to the greatest extent possible among both the researchers and the participants.

Hence, the innovation of PRA stands in the increased focus on the behavioural aspects of the researcher towards both the locals and himself. The creation of trust and mutual respect between the outsiders and the locals remains one of the most important underlying element in a PRA (Chambers, 2005). Transparency and honesty about who the outsiders are, what they are doing and why they are doing it should be part of the earliest stages of the research process (Chambers, 2005). Furthermore, double-side learning permits to enlarge the focus of the research and to disclose new interpretations and perspectives on the research context (Chandra, 2010). Locals are believed to own an exceptional capacity of modelling and quantifying many of the variables that outsiders might find difficult to understand (Chambers, 2005). Indeed, many PRA tools can be applied: mapping, seasonality analysis, matrix scoring, questionnaire and semi-structured interview (Chandra, 2010). To conclude, the diversification of perspectives coming from the multi-faceted approach of PRA appears to be the optimal strategy to be used in the smallholder community context. Indeed, the use of multiple tools and techniques reduces research bias and produces stronger and more relevant data to be shared within the community (Freudenberger, 1999).

Workshop at CEA and Vulnerability analysis

ANF decided to implement the “agricultural adaptation to climate change” workshop at its Agricultural Training Centre, starting with a pilot one then continuing with two others. The main purpose of the workshop was to teach farmers coming from smallholder communities situated in the Dry Corridor of Nicaragua about climate change, its impacts and the different agricultural techniques they could implement in their farms to face climate change. The workshop plan has been developed by Sayra Taleno and Amilcar Aguilar, researchers working respectively with CIAT (International Centre for Tropical Agriculture) and CATIE (Tropical Agronomic Centre for Investigation and Education), and based on the “Guide for the creation of rural plans for climate change adaptation strategies” developed by CIAT (Ortega & Paz, 2014).

The workshop creates the base for the understanding of climate variability, vulnerability and adaptation strategies thanks to the participation and collaboration of the farmers, connecting their local knowledge with the technical knowledge of the experts (Ortega & Paz, 2014). Its main goal is to raise the awareness of the participants about the climate change discourse while addressing the community vulnerability (Ortega & Paz, 2014). The entire method is founded on the concept expressed by Reidsma et al. (2010): “a sustainable action is a process guided from the communities and based on their priorities, necessities, knowledge and abilities which has to empower the people in order to make them able to face climate change”. The implementation of the workshop presents many benefits: cost-efficiency, flexibility, replicability and inclusiveness (Ortega & Paz, 2014).

The team of facilitators was formed of four members, supervisors of the workshop and in charge of leading all the workshop activities. In addition, members from the CEA staff gave their contribution in some logistic issues. The facilitators were Carla Hernandez, Berklin Martinez Rivas, Hector Alvarez and the author. The author was present during all the activities to monitor, learn and giving additional help in case of need. In the first pilot workshop, 19 smallholders participated. In the second workshop, the number of participants was 13 and in the third and last one 14. In the scheme below, a summary of the stages of the workshop is presented (fig. 10):

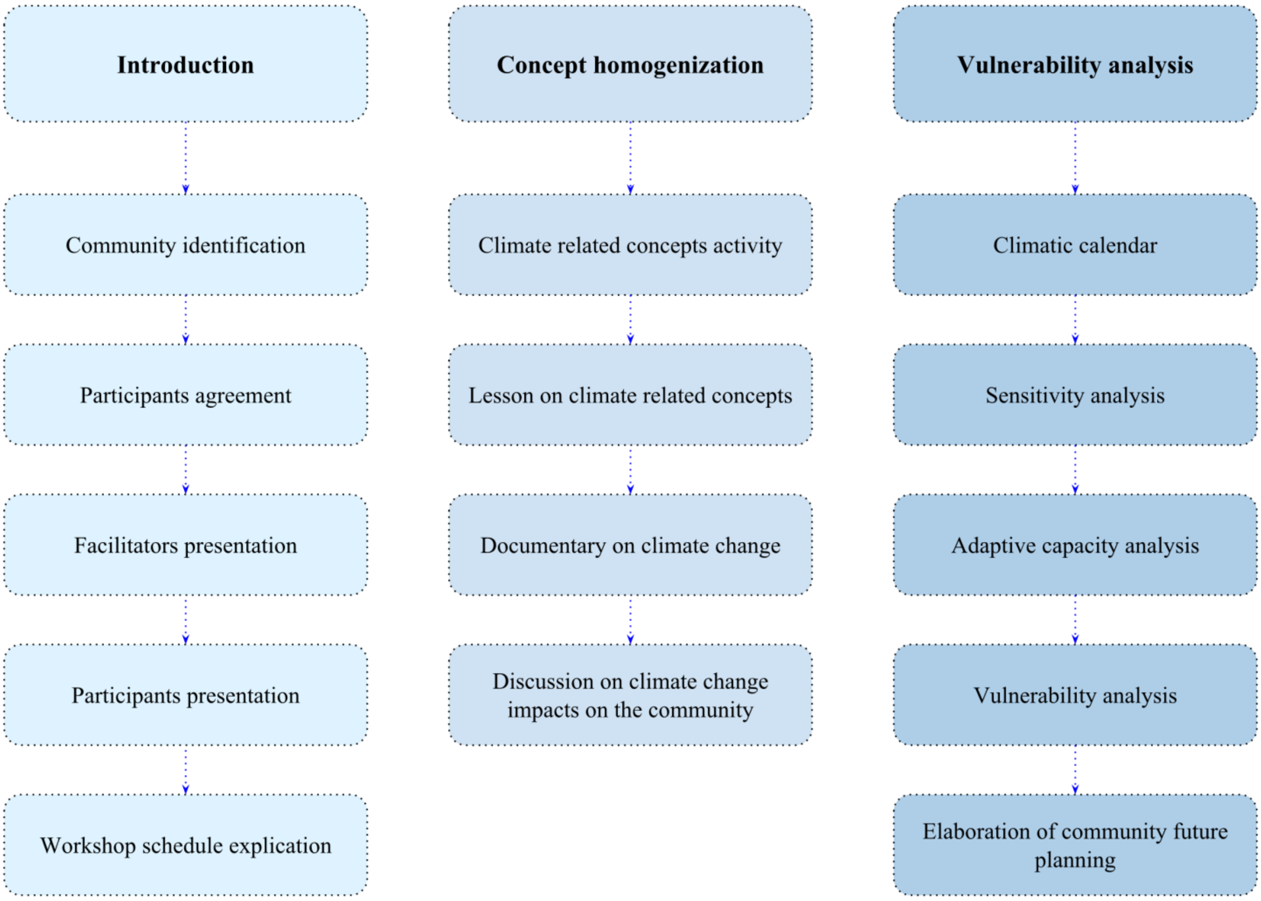


Figure 10: Workshop structure and different activities. Adapted from ANF on the base of the guide from Ortega & Paz (2014): Source: author's own.

Introduction stage

This first step looked at the explanatory initial part of the workshop. Here, both facilitators and participants got together to introduce themselves, their background and the motivation which led them to be part of the workshop. In fact, not only the facilitators were new faces for the community members, but the participants who worked together were not necessarily part of the same community. The facilitators introduced and explained the workshop structure and goals, its characteristics and the general idea behind it. A relaxed and open attitude from the facilitator side has been maintained according to the PRA principles of offsetting biases and progressive learning. Objectives, activities, logistics and expected results have been explained. Moreover, the inexplicit meaning of this introduction stage was to foster a rapid creation of friendly and collaborative relationships between everyone.

Concept homogenization stage

To guarantee a smooth and efficient implementation of the workshop activities, a process of creation and homogenization of concepts was necessary. Based on the definitions proposed by the IPCC (2014), the most important concepts were explained during the first meeting. An attempt of simplification of the concepts has been made in order to reach the greatest number of participants and to stimulate everyone's interest in the topics. The main explained concepts were: climate, weather, climate change, greenhouse effect, sensitivity, adaptive capacity, vulnerability and adaptation.

This stage reflected the integration of the cornerstone principles of PRA. In particular, the principles of facilitation and shared information have been stressed. In fact, the concept homogenization permitted to create a common and clear perception around the main themes tackled during the workshop, hence privileging both facilitators and participants to be part of a learning process which raises from the same ground. The friendly and relaxed attitude of the facilitators and the attempt not to result too strict in dictating the righteousness of the explained concepts encouraged interesting discussions within the participants. Moreover, group discussions allowed exploring the climate change perception of the participants and identifying the most diffused misunderstandings on the topic. Participants have been asked to reflect on the changes in climate variability they experienced and the variations of the yield trends they observed in the most recent years.

Vulnerability analysis stage

This stage started addressing the smallholders perception of climate change according to their experience. Developed as a group activity, the participants were asked to create a climatic calendar simply assigning climatic events to a premade calendar, in a monthly division. Basically, a certain characteristic climatic event was assigned to every month. The same activity has been repeated twice, once considering the usual climate of the northern region of Nicaragua, once considering the observed variations in climate in the last 10 to 20 years. The advantage of this stage relied upon the possibility to directly understand how smallholders are experiencing and perceiving climate change and which climatic events they observed in recent years. The results of the climatic calendar were used as the base for the selection of the main natural events in the vulnerability questionnaire. Moreover, a comparison between perceived climate change and climate change modelling studies was done to address differences and similarities between real and experienced climate change related events.

The vulnerability analysis questionnaire was based on the "Guide for the creation of rural plans for climate change adaptation strategies" (Ortega & Paz, 2014), together with the suggestions of Sayra Taleno who worked as the main consultant for the development of this project. The distinctive approach was to focus on the natural elements (variables) of the system, in this case the smallholder communities, in order to address the perceived sensitivity and adaptive capacity. For instance, some of the variables were superficial water resources, grass pasture, maize and beans. Recalling the theory previously introduced, the vulnerability has been calculated as the difference between sensitivity and adaptive capacity, according to the formula:

$$V = (S\text{-}AC)$$

Where V = Vulnerability, S = Sensitivity, AC = Adaptive Capacity. from Ortega & Paz (2014).

This formula was applied to every single variable to calculate its vulnerability and consequently the vulnerability of the entire system. Initially, the three most relevant natural events among the ones individuated during the climatic calendar have been selected. This step referred to the analysis of the exposure to climate change, otherwise absent in the formula. Then, the questionnaire has been filled with those three events in the correspondent slot and distributed to every participant. For the sensitivity analysis, the respondents were asked to allocate for every variable a number ranging from 1 to 3 or to leave the slot empty in case the variable was not existent in their community. 1 meant that the variable has not observed being affected by that correspondent natural event. 2 meant that the variable has been affected to a tolerable extent. 3 meant that the variable has been highly affected by the natural event. The individual sensitivity score per variable corresponded to the sum of the three values given per each natural event. The second part of the questionnaire regarded the adaptive capacity analysis. Similarly, the respondents were asked to allocate for every variable existent in their community a number ranging from 1 to 3. In this case, 1 meant that no adaptation strategies have been implemented for that specific variable to avoid negative impacts caused by the correspondent natural event. 2 meant that the adaptation strategies implemented have not been sufficient to avoid those negative impacts. 3 meant that the adaptation strategies implemented have been sufficient. Again, the individual adaptive capacity score per variable corresponded to the sum of the three values given per each natural event. In the Annex II, the questionnaire sheet can be found. It was possible to address the sensitivity per variable, the sensitivity per natural event, the adaptive capacity per variable and the adaptive capacity per natural event. The total scores of sensitivity, adaptive capacity and vulnerability per variable have been calculated as the averages of the individual scores per variable.

Structured interviews with smallholders

In addition to the workshop, structured interviews were conducted with every participant in order to identify the status of the target of this study. In structured interviews, each respondent is asked the same questions in the same order and with the same wording (Corbetta, 2003). The advantages of structured interviews are considerable, especially regarding this stage of the data collection. Firstly, they are time-efficient compared to other types of interviews as the questions are specific and logically connected (Doody & Noonan, 2013). Moreover, bias and subjectivity are generally limited and the control of the interviewer over the process is strong (Doody & Noonan, 2013). The set of questions was prepared a priori and adjusted after the first pilot workshop. When formulating the questions, the concept homogenization stage has been taken into account in order to choose adequate and simple wording for a clear understanding of the questions. The interviews addressed various elements of the community members status. The entire topic list can be observed in the Annex I. Regarding the question on the barriers that impede to implement different adaptation strategies, a quantitative answer had to be formulated for each of the identified barriers. The barriers have been selected on the base of prior literature analysis. The answer could range from 0 (the barrier is not existent) to 2 (the barrier is of major importance), where 1 corresponded to an existent barrier which is not particularly influent in limiting the respondent's possibility to implement new adaptation strategies. This last quantitative approach allowed for a more precise analysis of which barriers are the most urgent to be solved, at least according to the community perception.

Adaptation strategies selection

The identification and classification of adaptation strategies covered a fundamental role in this research. The development of the identification and ranking frameworks for adaptation strategies which has been followed in this stage was based on the literature introduced in the theoretical background. These frameworks also represent a tool ANF could use for identifying and classifying new adaptation strategies. In the identification framework, the three scales (plot, farm and landscape) were suggested by Harvey et al. (2014). The timeline was inspired by the distinction between short-term and long-term proposed by Vermeulen et al. (2012). The timeline goes from 1 month to 16 years, and it has been developed following an almost exponential trend in order to simplify the table visualisation.

The ranking framework was organized on the base of a multi-criteria analysis (MCA), an approach which allows comparing different options across several dimensions or criteria thanks to a scoring system (Huang et al. 2011). The total score per option is calculated as a linear sum of the single score obtained for each criterion (Huang et al. 2011). The multi-criteria analysis represents a complementary approach to the participatory one introduced earlier. In fact, the open and collaborative nature of PRA is integrated with the stricter analytical capabilities of MCA (Mendoza & Prabhu, 2005). The criteria have been extracted by the studies of Vignola et al. (2015) and Smit & Skinner (2002), previously introduced. The criteria have been prioritized depending on their potential contribution to nullifying the identified main barriers. In this way, the absence in the literature of a quantitative weighting system to prioritize the different criteria has been compensated.

The analysed adaptation strategies included the entire set of adaptation strategies ANF makes available. The choice of these adaptation strategies was based on the availability of funds and expertise at the disposal of ANF's Agriculture and Rural development department. Their classification in the two frameworks was the result of desk research on the most recent scientific literature. The most promising adaptation strategies were selected as the ones obtaining the highest total scores in the ranking framework.

To identify the most feasible adaptation strategies and finally answer the main research question, the selected most promising strategies have been compared with the findings of the previous steps of the research. The selected adaptation strategies should have contributed to decreasing the vulnerability of the most vulnerable variables. Moreover, they should have satisfied the greatest number of prioritized criteria.

Ethical considerations

Thanks to the author's fluency in the Spanish language, both the interviews and questionnaires were formulated in Spanish, in order to permit the respondents to have a proper understanding of the topics discussed. Honesty and transparency about the research aim and process have been ensured. Moreover, interviews and questionnaires were anonymous and the information treated in a strictly confidential manner. Respondents were ensured of dignity, safety, privacy and asked the consent to participate. The key informants were asked the consent to use the information they provided. The right to withdraw from the research at any moment was given to every participant. The respect of ethical and cultural standards was guaranteed through the knowledge acquired in a preliminary meeting planned by ANF with its main partners and some representatives of the communities, where the author participated.

Results

The following chapter presents the results of this research. The results are organized per sub-question, each one corresponding to one paragraph. The results of the pilot workshop are not taken into account in this chapter, although they have been analysed in order to improve the quality of both the structured interviews and the questionnaire.

The smallholder communities

Sub-q.1: Which are the main characteristics of the smallholder communities?

It was possible to collect data on the status of the smallholders and the characteristics of the communities. The age of the participants varied within a really wide range: the youngest was 15 years old, the oldest was 68 years old. The average age was 36.9 (s.d. 17.27). Only 2 participants were women. The level of education of the participants also varied. 12 smallholders were educated to a primary level. 9 of them completed the secondary school. 6 attained an academic degree. 2 of them completed courses separated from the university career.

All the respondents were employed in the agriculture sector. Only 3 smallholders declared to work part-time in different fields (phone repairer, cook, dentist assistant). Even in these three cases, agriculture remained the main source of income. Within the farm, the process of decision-making was led by the participant alone in 11 cases. 7 smallholders declared to consult the family before taking a decision. 7 smallholders declared to be supported by only one familiar, always a male relative, either the father, the uncle or the brother. In 5 cases the decision-maker was someone else, either an older member of the family or the farm's owner.

The farms were described as having similar dimension. The results are expressed in hectares (ha), converted from manzanas (ma), the Nicaraguan unit of area where *1 ma = 0.704 ha*. The average farm dimension was 4.58 ha (s.d. 9.15). The high value for the standard deviation was due to the two answers clearly out of the common range. In fact, the average dimension without extremes was 2.35 ha. The results are shown in the table (Fig.11).

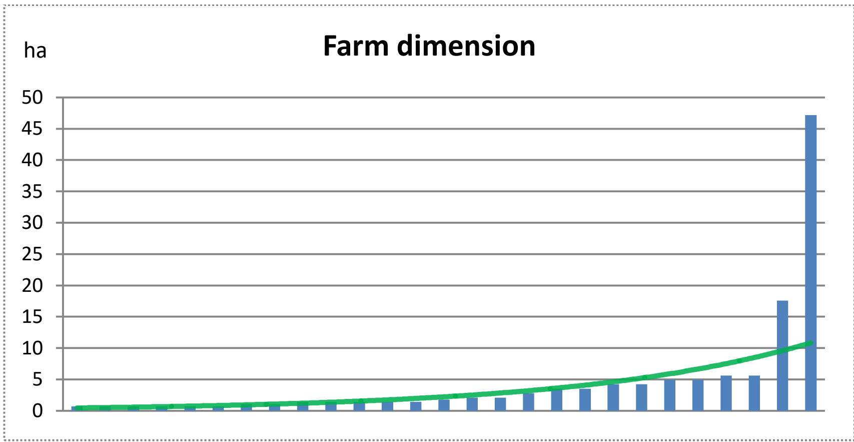


Figure 11: Dimension of the farm expressed in hectare. Source: author's own.

Production was mainly intended for self-consumption. 14 smallholders stated that in favourable years, part of the production can be sold in local food markets. 15 smallholders reported that the soil condition of their farm is good or really good. 6 defined the soil condition as regular. 6 complained about having infertile or excessively rocky soil.

The diffusion of the main crops production presented strong similarities. Apparently, the majority of smallholders opt for the same crops. Maize and beans represent the most diffused crops, covering respectively the 88.9 % and the 85.2 % of the cases. In the following graph, the results concerning the diffusion of the main crops are shown (Fig. 12). Under the category 'other' are included rice, cacao, guayaba and citrus.

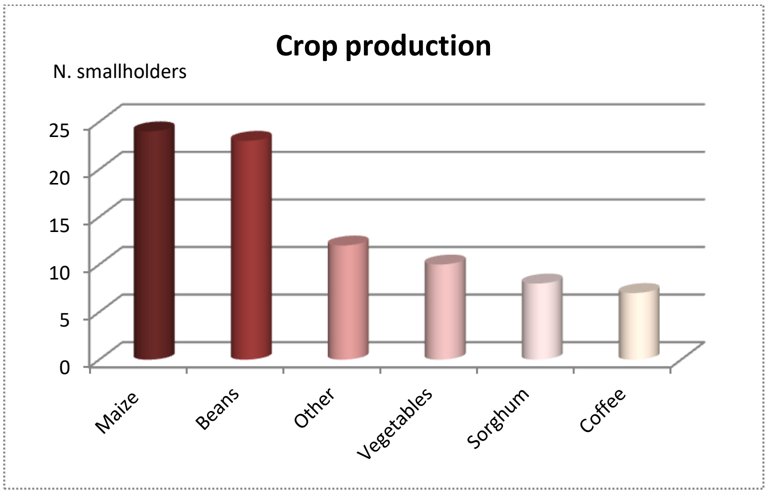


Figure 12: Production of main crops per number of smallholders. Source: author's own.

The information gathered from key informant interviews anticipated and confirmed the observed characteristics. The production is not sufficient to guarantee an extra income from selling products because of the scarce technology and the reliance on family labour. The crop production patterns are very similar in the farming systems in the Dry Corridor area, where maize and beans represent the chief staple food.

Climate change perception and experienced climate change impacts

Sub-q.2: How do smallholders perceive and experience climate change impacts?

The workshop activities together with structured interviews clearly showed a strong lack of knowledge regarding the main concepts related to climate change. Many of them were not known or barely known. A lot of confusion was generated by the misunderstanding of concepts. In particular, climate change was not recognized as a combination of different interconnected phenomena, but rather as a synonymous of either temperature increase or rainfall reduction. Moreover, the causes and the mechanisms behind climate change were unknown to the majority of the participants. A severe lack of knowledge was observed around the scale under which climate change occurs and its cause-effect relation with anthropogenic activities. Interestingly, long discussions emerged around the role of the most developed countries and their contribution to climate change, especially in comparison with the position of Nicaragua.

During the group discussions the participants identified the major unusual climatic events they observed in the community. An almost total agreement has been found among participants, probably connected to the geographical proximity of the respondents' communities. The smallholders expressed that the region is becoming drier as a result of both rainfall reduction and higher temperatures. The soil is highly suffering erosion. The length of the dry season is increasing, and unexpected rain events happen during the dry season. The length and regularity of the Canicula, dry period occurring during the wet season, has drastically changed. The main events individuated during the formulation of the climatic calendar were: seasonal delay, non-constant rain, temperature increase, more intense rainfall and unusual rain during the Canicula period. Total agreement of the participants has been reached on the selection of the events.

As a result of the experienced climate change impacts, the majority of the smallholders highlighted severe damages to agriculture. Yields decreased in the last years due to rainfall reduction and unstable distribution of rainfall which undermine the productivity of rain-fed farms. All the major crops like beans and maize are highly affected by climate change. The planting season is slowly moving from Primera to Apante, where the new climatic conditions are believed to be more favourable.

Key informants clearly confirmed the impacts of climate change on Nicaraguan agriculture, underlining the particular exposure of the communities situated in the Dry Corridor. B.M. Rivas reported having observed how farmers experienced difficulties with seasonal delay. As the rainy season is moving more and more towards the end of May (last week), farmers started to plant several weeks later than usual. Once the heavy rains come, crops are not developed enough to resist and the losses are huge. Water scarcity is influencing both yields and livestock.

"Probably the most dangerous threat comes from the reduction and redistribution of rainfall during the year."

(H. Alvarez, Professor in agronomy)

Existing adaptation strategies

Sub-q.3: Which adaptation strategies for smallholder communities have already been implemented?

Quite surprisingly, the majority of the respondents declared to have implemented one or more adaptation strategies. This indicates the positive effects of ANF's previous interventions in these communities. However, the strategies are rather simple. 11 respondents applied only one or two techniques of the entire soil conservation approach. They said to have quit vegetation burning and to have integrated crop rotation or cover crops. Only 3 respondents opted for irrigation and 1 for water harvesting. Biodigesters have already been built in two of the farms. ANF's staff confirmed the existence of biodigesters pilot projects. A few respondents declared to have changed crop varieties, opting for climate-resistant varieties, and others to have implemented reforestation or agroforestry.

Adaptation strategies	Number of smallholders
Irrigation	3
Water harvesting	1
Biodigester	2
Soil conservation	11
New crop varieties	3
Reforestation	1
Agroforestry	1

Figure 13: Already implemented adaptation strategies. Source: author's own.

Despite the large diffusion of certain adaptation strategies, frustration and doubts about their efficiency were expressed. Many smallholders admitted that despite the initial improvements, the strategies they implemented have not been sufficient to face the yields decrease. Where a biodigester was used, smallholders showed enthusiastic satisfaction with the outcomes of the project. H. Alvarez shared the positive approach towards biodigesters although he prioritized biointensive agriculture as a more comprehensive and effective adaptation strategy. In particular, the improvement of soil characteristics is meant to provide enormous benefits with minimal initial investments.

Barriers against the implementation of adaptation strategies

Sub-q.4: Which barriers are the most influential in limiting the implementation of potential adaptation strategies?

The main barriers against the implementation of adaptation strategies identified in the literature introduced in the theoretical background chapter have been grouped in five main categories: Economic, Lack of knowledge, Mistrust on the necessity of adaptation strategies, Bureaucratic and Respect of traditions. The results provided from the structured interviews are shown in the scheme (Fig.13) and graph (Fig.14):

Economic	Lack of knowledge	Mistrust on necessity	Bureaucratic	Respect of traditions
1.67	1.11	0.0	0.44	0.19

Figure 14: Barriers total scores calculated as the average of the individual scores. Source: author's own.

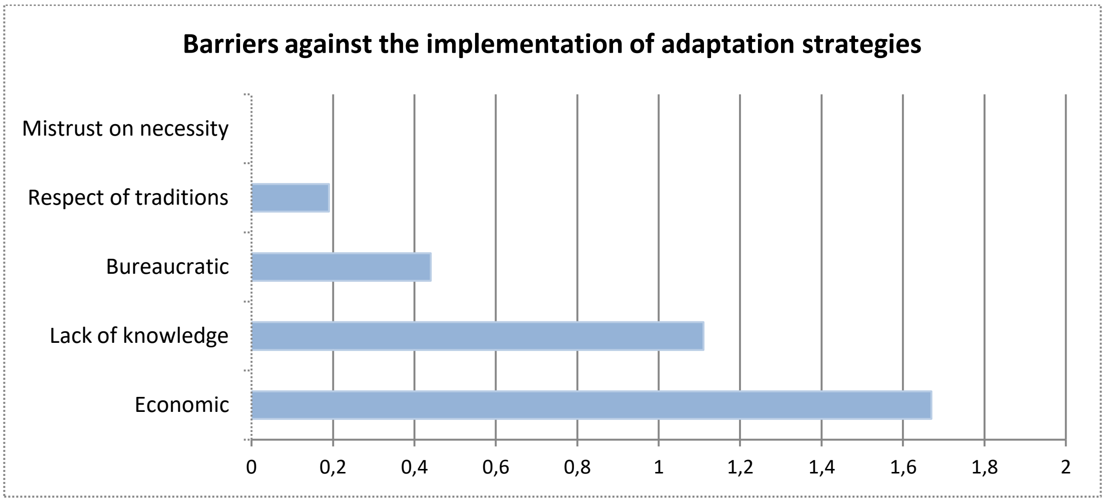


Figure 15: Barriers against the implementation of adaptation strategies, graphic visualization. Source: author's own.

The economic and the lack of knowledge barriers score more than the double any other. The predominance of these two barriers was confirmed by the key informants. S. Taleno believes that the lack of knowledge is the result of the combination of both poor education and lack of information. Data relative to climate change and agriculture are scarcely produced and rarely divulgated. Climate databases are difficult to be accessed and understood, especially for uneducated people.

"Moreover, I believe that another problem is the lack of information, both in terms of non-communication and non-existence."

(Sayra Taleno, CATIE agriculture consultant)

Lack of knowledge and the economic barrier are also interconnected barriers. Although smallholders perceive the necessity of developing strategies to cope with climatic variations, they are not able to understand the link between seasonal issues and long-term effects of climate change. Hence, they opt for inexpensive short-term solutions rather than long-term planning. Being aware of climate change is just an initial step and is not sufficient to guide rural development towards adaptation.

"They believe in climate change, but they don't own the necessary knowledge to really understand it. They need to adapt and they need to understand the urgency of doing it."

(B.M. Rivas, CEA responsible)

The low score for the bureaucratic barrier is due to the large freedom that farmers possess in Nicaragua regarding decision-making in the agriculture sector. Only two national laws were mentioned, during both structured and key informant interviews: *No quema* and *No deforestación*. *No quema* refers to a law approved on the 18th of March 2011 which regulates the burning of agricultural sub-products, a habit of many farmers which often causes forest fires (Vallecillo, 2012). *No deforestación* refers to a set of regulations grouped under the law n.462 on the conservation and sustainable development of the forest sector

(Marín et al. 2007). Both the laws were considered a limitation against possible agricultural land expansion and crop migration.

Respect of tradition was completely neglected by the totality of respondents. As K. Poe reminds, from the smallholder perspective decision-making becomes a process driven by surviving necessities and dictated by scarce knowledge sources. Thus, the tendency of the farmers to maintain the same agricultural practices does not derive at all from their will to follow local traditions, but rather from the intrinsic limitations of the community environment.

"Remember that they have to survive in harsh conditions…. It is just that their decision-making, for example the choice of which variety to plant in which season, is mainly based on local knowledge and personal observation."

(K. Poe, director of ANF Agricultural Department)

In order to gain additional insights into the barrier lack of knowledge, the average scores have been calculated again, divided per education level. Apparently, the almost equal average results do not show a relationship between the level of education and the perceived lack of knowledge regarding climate change adaptation and adaptation strategies.

Education level	Number of smallholders	Average score for the Lack of knowledge barrier
Primary school	12	1
Secondary school	9	1.3
Academic degree	6	1

Figure 16: Average score for lack of knowledge per level of education. Source: author's own.

Climate change vulnerability of smallholder communities

Sub-q.5: What is the vulnerability to climate change of the smallholder communities?

The quantitative results obtained from the questionnaire indicate the degree of sensitivity, adaptive capacity and consequently vulnerability for every variable (Fig.18). The results are presented considering the total scores per variable. Individual and total scores can be observed in the Supplementary material. The scores per variable have been singularly reduced of 1 point in order to avoid the bias of the original questionnaire and evaluate the variables in a range 0 to 2 instead.

It resulted that the variables with the highest score in terms of vulnerability were superficial water resources, planted forest, grass pasture, maize and beans (respectively: 1.92; 1.56; 2.62; 1.41; 1.69). Fruit, vegetables, undergrowth and coffee obtained the lowest scores (respectively: 0.30; 0.25; 0.13; 0.28). Vulnerability never reached 0 or a negative score. The sensitivity to climatic events never fell lower than 1.5 (Cacao's score), suggesting the perceived widespread impacts of climate change on the farm resources. Adaptive capacity presented similar patterns to sensitivity if the scores per variable are compared. For instance, maize, beans, fruit, vegetables and underground water resources all showed the highest scores in both sensitivity and adaptive capacity.

The label of each column in the graphs represents the number of participants who actually assigned a value for that variable. In fact, the averages per variable have been calculated on the base of the number of respondents who assigned a value to that certain variable. It resulted that only 4 smallholders are producing cacao and only 5 rice. On the other hand, 27 smallholders produce maize and 26 beans. This lines up with the analysis of the smallholder communities made to respond the first sub-question. In fact, while maize and beans resulted to be the main crops, cacao and rice have been scarcely cited. The fact that coffee is actually present in 17 farms means that its production is relatively minimal in many of the farms, as it has only been mentioned 6 times as a main crop during the structured interviews. Interestingly, the highest scores for vulnerability belong to the most diffused farm resources. In the following table (Fig. 17) are presented the sensitivity, adaptive capacity and vulnerability scores per category, obtained as the average of the total scores for the variables belonging to the same category.

	Water resources	**Forest**	**Livestock**	**Agricultural crops**	**Minor crops**
Sensitivity	3.29	2.93	3.09	2.62	2.76
Adaptive capacity	1.76	1.52	1.10	1.59	2.39
Vulnerability	1.54	1.42	1.99	1.03	0.37

Figure 17: Results for Sensitivity, Adaptive capacity and Vulnerability per category obtained as the average of the total scores for the variables belonging to the same category. Source: author's own.

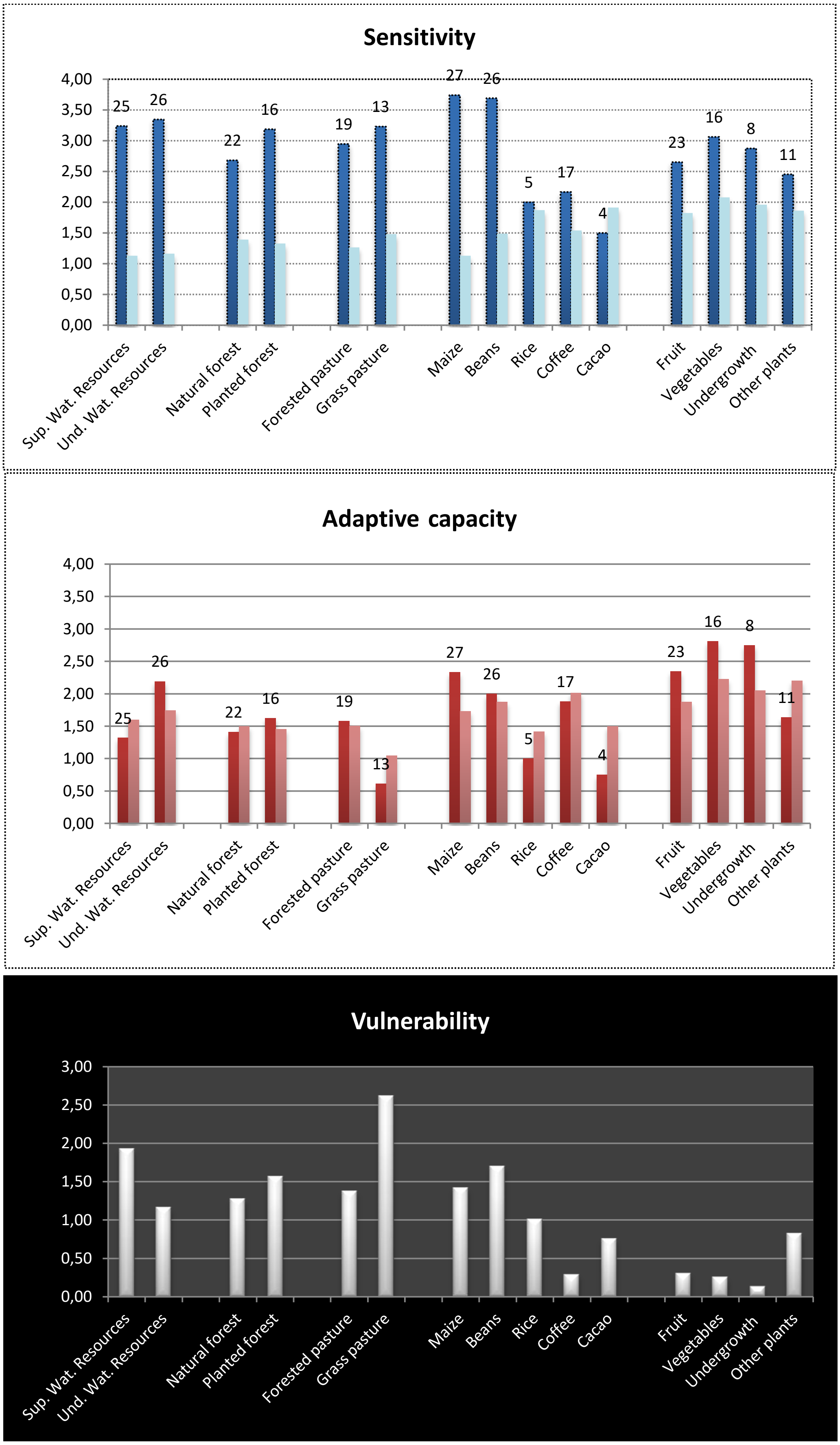


Figure 18: Results for Sensitivity, Adaptive capacity and Vulnerability per variable obtained from the questionnaires, calculated as the averages of the individual scores per variable. In the light-coloured columns, the values of the standard deviation. Source: author's own.

Adaptation strategies

Sub-q.6: Which adaptation strategies can be identified as most promising for a successful implementation in the smallholder communities?

ANF proposes and supports different adaptation strategies which are believed to be applicable in smallholder communities in the Dry Corridor of Nicaragua. The identification and ranking frameworks adopted in this study aimed to help ANF in the selection of these strategies through the understanding of their main characteristics. In the following sub-paragraphs, the adaptation strategies proposed by ANF are introduced, analysed and classified.

Biodigesters (BD)

ANF implements a system of biodigesters offered by Sistema Biobolsa, leading company in the production and distribution of biodigesters operating in Latin America (SistemaBio, 2018). The company aims to propose a comprehensive solution against water and air contamination, improper waste management, global warming, deforestation and use of chemical fertilizers (SistemaBio, 2018). In fact, biodigesters are meant to bring positive impacts like conservation of natural resources, reduction of GHG, reduction of health risks, increase of soil quality and long-term economic benefits (SistemaBio, 2018). This technology is specially designed for the small-scale context of farmer communities (SistemaBio, 2018). A biodigester is a modular system which combines the action of anaerobic digestion reactors with biological aerobic filters in order to decompose organic waste (Flesch et al. 2011). The performance of biological processes permits to obtain two important products: biogas and organic fertilizer (Garfi et al. 2016). The biogas can be used for heating systems, usually cooking stoves, while the organic fertilizer represents the organic alternative to any kind of fertilizer, ready to be used directly on site. The lifespan of the system is meant to be at least 35 years, and the initial investment quite high. It is expected that the production of biogas and organic fertilizer is functioning after only three weeks from the installation.

The role of biodigesters is believed to go further the simple clean production of energy and fertilizer as it can be enclosed under the broader perspective of sustainable farming (Preston & Rodriguez, 2002). The already mentioned environmental benefits can be coupled with equally important elements like the empowerment of the communities and the local employment (Preston & Rodríguez, 2002). In a series of recommendations for the introduction of biodigesters in Latin America, Garwood (2010) underlines how the success of many case studies was determined by the identification and integration of socio-cultural factors like the families' cooking habits, their motivation, involvement in the construction of the biodigester and their willingness to assimilate new habits. The social benefits of biodigesters include healthier conditions for the women as a result of the air pollutants removal and time-gaining for extra activities due to the reduction of time spent for collecting solid fuel (Garfi et al. 2016). The biodigester represents an adaptation strategy which satisfies criteria like the diversification of income generation and the use of local inputs. It occurs on the landscape scale.

Biointensive agriculture (BI)

The modern biointensive agriculture developed initially in Palo Alto, California, as a program of sustainable farming conducted by the researches of Ecology Action (GrowBiointensive, 2018). This strategy combines the maximization of the yield with the minimization of resource consumption through the improvement of soil fertility (Jeavons, 2001). In particular, the main principles of biointensive agriculture are: high productivity; advancement of a healthy environment; environmental stability; resource conservation; flexibility; local empowerment (Jeavons, 2001). Although different existing methods can be enclosed in the general concept of biointensive agriculture, the common key element is the incorporation of sustainability into productivity (Earles & Williams, 2005). In other words, the strength of this adaptation strategy is that it offers a set of sustainable practices while guaranteeing a high economic value of the same practices (Earles & Williams, 2005). Hence, biointensive agriculture can appear particularly tempting within the smallholder communities, where low productivity is often the main challenge to be faced (Netting, 1993). The potential of the system includes up to 200-400 % increase in caloric production, 70% reduction of water consumption and a 50-100% reduction of purchased fertilizers (Jeavons, 2001). According to Jeavons (2001) the structural elements of biointensive agriculture are:

- Deep soil preparation to enhance soil structure.
- Feeding the soil with compost.
- Using organic fertilizer.
- Close spacing in the crop planting.
- Plant symbiosis.
- Open-pollinated seeds for natural breeding.
- Carbon farming.
- Calories farming.
- Thinking the system as a whole.

ANF's idea of biointensive agriculture traces the abovementioned principles. Biointensive agriculture occurs on a plot scale, as it mainly comprehends agricultural approaches focused on the crop growth. It satisfies criteria like improving the farm productivity, use of local and renewable inputs and the diversification of income generation. Although different crops have different growing periods, it can be estimated that an entire production cycle might cover a period between 4 and 6 months (Jaspers et al. 2012).

Agroforestry (AF)

Agroforestry is recognized as a promising approach towards resource management which brings together sustainability principles and rural development of resource-scarce farmers, primarily in tropical areas (Schroth, 2004). It embraces different land-use practices promoting biodiversity and the biological equilibrium of ecosystems (Schroth, 2004). Agroforestry usually refers to the combination of agricultural products with trees or shrubs that are grown among or on the side of the crop (Young, 1997). Its adaptation and mitigation benefits can be found in the fields of increased biodiversity, sustainable land management, carbon storage, deforestation reduction and improved human nutrition and health (Schroth, 2004).

Agroforestry is believed to provide a mean to diversify the agricultural production while increasing climate resistance of smallholder farming systems (Verchot et al. 2007). The inclusion of a tree-based system represents a key adaptation strategy to cope with rainfall variation and extreme weather events (Verchot et al. 2007). Deep roots help to explore deeper soil layers, extracting important nutrients and water, increasing soil porosity and soil retention while reducing runoff (Jose, 2009). Moreover, agroforestry systems have higher evapotranspiration rates compared to both pastures and row crops, thus contribute to maintaining better soil conditions and aeration (Jose, 2009). Pattanayak & Mercer (2002) highlight that despite the considerable economic value of agroforestry systems the initial costs and labor might be very high (Pattanayak & Mercer, 2002).

It is likely that smallholders are not willing to invest in agroforestry because of either their lack of knowledge concerning agroforestry's long-term benefits or lack of capital (Pattanayak & Mercer, 2002). Hence, public support which encourages private agroforestry seems to be necessary (Pattanayak & Mercer, 2002). Moreover, the time required to experience tangible benefits from agroforestry is generally higher than many other adaptation strategies, further decreasing the interest of smallholders in this practice (Schoeneberger et al. 2012). This adaptation strategy occurs on the landscape level, as also specified by Harvey et al. (2014). Although the impossibility to give an exact estimate of the time required for this strategy to be effective due to the vast range of species which can be selected, it is unlikely that any benefit is expected before four years from the planting (Tscharntke et al. 2011; Price, 1995).

Irrigation (I)

As previously introduced, smallholder communities located in the Dry Corridor will face water scarcity during the dry season and excessive precipitation during short periods, with severe consequences for agricultural production. Considering that the majority of the farms are rain-fed systems, irrigation can represent an optimal strategy to regulate and manage the levels of water (Rockström et al. 2010). Although the existence of many irrigation methods, ANF mainly proposes drip irrigation, already implemented in a few farms.

Drip irrigation is a micro-irrigation method developed to maximize water saving and nutrient absorption (Goldberg et al. 1976). Water emitters situated either on or immediately below the soil surface allow water to drip slowly close to the plant roots, limiting evaporation (Dasberg & Or, 2013). Drip irrigation presents many advantages: minimization of fertilizer and nutrient loss due to reduced leaching; water efficiency; reduced soil erosion; reduced weed growth; more uniform irrigation (Dasberg & Or, 2013). On the other hand, the system requires constant maintenance and the initial costs can be prohibitively high (Narayanamoorthy, 1997; Cetin et al. 2004). In many cases, the introduction of drip irrigation systems in smallholder communities did not achieve positive results as a consequence of low understanding, high maintenance requirements and low technical support (Belder et al. 2007; Shah & Keller, 2002).

Thanks to the limited farm dimension of the smallholder communities, ANF's previous experiences showed that the application of an irrigation system can be completed in a maximum of two weeks. This adaptation strategy occurs on the plot scale and it satisfies criteria like improving farm productivity and reduction of extreme weather event impacts (heat waves and droughts) but it can undermine the stability of local water resources.

Crop diversity increase (CD)

The last adaptation strategy ANF includes in its rural development projects regards the increase of crop diversity. As shown in the previous paragraphs, smallholder communities present a high degree of similarity regarding the selection of cultivated crops. Considering the climatic characteristic and the predicted impacts of climate change on the agriculture systems of the Dry Corridor of Nicaragua, ANF decided to focus on the integration of a species of indigenous cactus from Latin America, the Pitaya.

Pitaya is a columnar cactus which produces edible fruits, both in wild and domesticated conditions (Pimienta-Barrios et al. 1997). Its inclusion in farming systems is relatively recent and due to the low inputs of water and nutrients it requires (Pimienta-Barrios et al. 1997). Columnar cacti are widely regarded for their ecological value in ecosystem conservation, as they support diverse populations of pollinators, seed scatterers and frugivorous (Williams et al. 2014). Specialized metabolism together with the capacity to store massive amounts of water make Pitaya resilient to stressful climatic conditions (Williams et al. 2014). Pitaya can even grow in infertile soil which is unsuitable for other crops (Pimienta-Barrios et al. 1997). Because of its high drought tolerance, it is considered a climate-smart fruit and a valid species to be implemented in climate-vulnerable environments (Mani & Suresh, 2018). The fruit production can start after only one year from planting, although market profitability is generally not convenient before 10 years due to the initial high costs (Pimienta-Barrios et al. 1997). Productivity can last up to 100 years, making Pitaya a strategy of which benefits can be experienced in the long-term (Zimmerman et al. 2013). K. Poe highlighted how the economic value of Pitaya remained high and stable in recent years. Increasing crop diversity through the introduction of Pitaya represents an adaptation strategy which occurs on the farm scale and has a time requirement of at least one year before being effective. It enhances the farm-level innovation while diversifying the income generation and improving the farm productivity.

Education (E)

Although it is not generally considered an adaptation strategy, in the context of smallholder communities education holds an important role, especially according to ANF's perspective. ANF wants to push towards a stricter focus on farmers' education, meant to be the cornerstone of any successful project implementation. Considering the results presented in the previous paragraphs, it is evident how the lack of knowledge and scarce education still represent two of the most striking limitations against the adoption of adaptation strategies. Thus, ANF wants to integrate educational and training projects within the wider puzzle of climate resistance rural development.

UNESCO (United Nations Educational, Scientific and Cultural Organization, 2015) stated that education holds a strong value in the climate change discourse. Education provides benefits on multiple scales. It helps policy-makers realizing the urgency of taking actions to face climate change and it raises awareness of local communities regarding climate change impacts (UNESCO, 2015). Adaptation in local rural development requires a holistic approach which incorporates both policy-makers and communities, hence the knowledge of climate change becomes fundamental on both levels (Grothmann & Patt, 2005). Farmer's education has been confirmed to have positive impacts on adaptation strategies by Knowler & Bradshaw (2007). Climate change education should not only focus on spreading knowledge but should include the development of useful skills: problem-solving, adaptive learning, planning skills and linkage of theory and practice (Davidson & Lyth, 2012). In the context of smallholder communities, the practical application of theory is a mandatory approach (Davidson & Lyth, 2012). Although promoting formal education seems to improve the community's adaptive capacity, developing practical abilities represents a faster and more efficient way to face climate change (Wamsler et al. 2012). Education can hardly be inserted in the identification framework, as it does not refer to any farming approach. Surely, the length of this strategy is largely variable, depending on the training duration. It satisfies many criteria as it contributes to increasing climate-specific knowledge and to empowering smallholders.

Identification framework

Plot	*I*		*BI*						
Farm					*CD*				
Landscape	*BD*						*AF*		
	1	**2**	**4**	**8**	**1**	**2**	**4**	**8**	**16**
	Months				Years				
	Timeline								

Figure 19: Identification framework for adaptation strategies. On the vertical axis the three scales classification proposed by Harvey et al. (2014), on the horizontal axis the timeline representing the time period needed for the adaptation strategy to be effective after its implementation, as suggested by Vermeulen et al. (2012). Source: author's own.

Prioritized criteria

Criteria	
Maintains or improves farm productivity	**Economic Barrier**
Increases or diversifies income generation	**Economic Barrier**
Requires affordable costs and labour	**Economic Barrier**
Respects local or traditional knowledge	**Lack of knowledge**
Fosters education and knowledge	**Lack of knowledge**
Empowers the community	**Lack of knowledge**

Figure 20: Criteria to be prioritized as connected to one of the main barriers against the implementation of adaptation strategies. Source: author's own.

Ranking framework

Criteria	BD	BI	AF	I	CD	E
Maintains or improves farm productivity*	+	+	+	+	+	.
Reduces the impacts of extreme weather events	.	.	+	+	.	.
Reduces crop pest and disease hazards	.	+	.	.	.	.
Increases or diversifies income generation*	+	+	+	.	+	.
Respects local or traditional knowledge*	–	.	.	.	.	+
Uses locally available and renewable inputs	+	+	+	–	.	.
Requires affordable costs and labour*	–	+	–	–	–	.
Develops farm-level innovation	+	.	.	+	+	+
Fosters education and knowledge*	.	.	.	.	.	+
Empowers the community*	+	+	.	.	.	+
Total score	+++	++++ ++	+++	+	++	++++

Figure 21: Ranking framework for the selection of adaptation strategies with the criteria extracted from Vignola et al. (2015) and Smit & Skinner (2002). The scoring system has to be read as follows: + indicates that the strategy positively fulfils the criterion, . indicates that the strategy is neutral compared to that criterion, - indicates that the strategy acts negatively compared to that criterion. The symbol * indicates the prioritized criteria. Source: author’s own.

The ranking framework shows how two strategies named biointensive agriculture and education obtained a higher total score compared to the others. Every adaptation strategy obtained a positive total score. Hence, the set of measures that ANF proposes present many adaptation benefits in favor of the smallholder communities. All criteria have been satisfied from at least one strategy.

The two strategies together satisfy the entire set of prioritized criteria, hence they can be confirmed as the most feasible adaptation strategies. In comparison with the results of the vulnerability analysis and the smallholder community characteristics, the following considerations can be done. Biointensive agriculture allows increasing the farm productivity, crop diversification and income generation. Hence, it positively contributes to several issues identified in the smallholder communities concerning the low productivity levels, low income and the persistence of traditional agricultural techniques. Moreover, the reduction of water use and the general improvement of the farming system functioning can help face the high degree of vulnerability of the water resources and the agricultural and minor crops. Biointensive agriculture opposes soil erosion and enhances crop resistance to climatic unusual events, decreasing the sensitivity of agricultural and minor crops. Education can strengthen the scarce understanding of climate change concepts showed during the workshops and create a better foundation for the future implementation of other adaptation strategies. Moreover, education fosters farm-level innovation which can lead to the development of measures apt to decrease the resources' vulnerability to climate change.

Discussion

This study was intended to identify the feasibility of existing climate change adaptation strategies within the dimension of the smallholder communities in the Dry Corridor of Nicaragua, while addressing their vulnerability. In order to answer the main research question, six different sub-questions have been formulated as different relevant aspects of the smallholder communities had to be taken into account. The most feasible strategies have been identified as biointensive agriculture and education. The climate change vulnerability reached high levels in every category, indicating a shared perception of the negative impacts of climate change on the farming systems. In order to implement new adaptation strategies, two main barriers have to be overcome: economic barrier and lack of knowledge. This chapter initially discusses the strengths of the research. Then, it highlights the relevance of the findings comparing them to the existing scientific literature. This paragraph is organized in the same order of the results chapter. Finally, the main limitations, possible improvements for further research and recommendations are examined.

The research's main strengths

The initiative to combine different approaches and to accomplish both qualitative and quantitative analysis exemplifies how it is possible to merge different branches of research on adaptation in agriculture. On the one hand, the participatory nature of the workshop guarantees a bottom-up strategy which generates information through the direct involvement of the farmers. On the other hand, the more detached perspective of desk research and multi-criteria analysis gives different insights on adaptation thanks to scientifically grounded theories. Thus, by coupling together two different but complementary approaches it is possible to define the local feasibility of adaptation strategies including both human and environmental elements. The usefulness of integrating a participative and a multi-criteria analysis is explained by Mendoza & Prabhu (2005) as a mutual strengthening of the two. The lack of rigour and the excessive simplification of a participatory approach are balanced by the accuracy of a criteria-based analytical support (Mendoza & Prabhu, 2005). Likewise, the scarce specificity of multi-criteria selection is compensated by a data collection process which incorporates the local perception of the farming system-climate change interaction (Mendoza & Prabhu, 2005). In other words, this type of triangulation allows contextualizing the existent scientific knowledge on agricultural adaptation under the narrower circumstances of the smallholder communities. As Shiferaw et al. (2009) claim, there is the urgency to provide smallholders with flexible adaptation measures suitable to specific niches which depend on perceived limitations and specific requirements.

Another interesting insight regards the possibility to develop a common goal for rural development, shared by the smallholders and generated through dialogue and discussion. Adaptation can shift from being an individual initiative undertaken by single farmers to a collectively accepted approach steering the future of climate-vulnerable farming systems. In fact, the respect of the PRA principles of sharing knowledge, progressive learning and openness reverses the research approach from extracting to empowering, making adaptation an accessible path for the smallholders (Mukherjee & Chambers, 2004). Adaptation goes through a process of collective learning based on horizontal interactions which consider smallholders and external actors on the same level. Here, constructive synergies can be created and smallholders can develop trust and a proactive approach towards the implementation of adaptation strategies. Holden et al. (1998) underline how resource-poor farmers struggle with long planning horizons and risk acceptance. If farmers decide to go through any sort of change, they want to be sure about the outcomes and they develop high expectations (Shiferaw et al. 2009). Hence, it becomes clear how the creation of trust around a common view on adaptive rural development can represent a key strategy to ensure the success of agricultural adaptation.

Relevance of the findings

On the smallholder community characteristics

The analysis of the smallholder status reflects a wide variability of factors like age and level of education. On the other hand, the identified similarities among the participants confirm the previously introduced characteristics of self-organization, self-consumption and reliance on local agricultural production. Although Berdegué & Fuentealba (2011) neglects the farm dimension to be a distinctive factor of smallholder communities, the findings show that for all but two cases the farm area stands close to the average of 2,35 he. Beans and maize largely represent the staple crops, consistently with Nowak et al. (2015). The fact that the decision-making process is confined in the family dimension underlines the restricted sphere of existence of the communities and the local condensation of the farming system stressed by Morton (2007).

On the perception of climate change

The strong agreement found in the identification of unusual climate events and climate variability establishes a shared perception of climate change impacts, although a high degree of ignorance exists in understanding how the climate system works and how it is interconnected with anthropogenic activities. A possible interpretation of this discrepancy is explained by Weber (2010) who identifies the obstacles impeding the transfer of scientific information on climate change from the academic world to the non-educated public. The main limitation comes from the intrinsic characteristic of climate change of being a statistical phenomenon, hence referring to average weather variables and long-term trends (Weber, 2010). Hence, personal evaluation of climate variability based on individual experience and memory of past events can be faulty as it embeds random weather fluctuations actually existing in the climate system (Weber, 2010). Expectations of change or stability also play a role in farmers' ability to understand climate trends, together with affective processing of climate observations (Weber, 1997). Apparently, associating adverse aspects of climate events with emotions like anxiety and fear influences the perception of climate change and shapes farmer decision-making (Weber, 1997). The scarce scientific knowledge on climate concepts can be related with the identified barrier of lack of knowledge, in line with the claims of Moser & Ekstrom (2010).

On the climate change impacts

The results show that smallholders are already experiencing the impacts of climatic patterns variation in accordance with future climate scenarios. Rainfall reduction and temperature increase have been identified by the participants as the causes behind the region becoming drier, exactly as expected by Imbach Bartol et al. (2012). The presence of uncommon climatic events has been confirmed, the most salient one being rainy events during the Canicula period. Moreover, seasonal delay and intensification of the dry season confirm the predictions of Aguilar et al. (2005). The effects of climate change on agriculture that have been found are yield reduction and the shift of the planting season from Primera to Apante. The findings confirm the crop suitability shift described in the two studies of Eitzinger et al. (2012) and Bouroncle et al. (2016). The areas where the crop suitability is believed to move from the Primera to the Apante identified by Eitzinger et al. (2012) is actually slightly moved to the east compared to the communities location (compare Fig. 3 with Fig. 7). Hence, the results of this research suggest a possible expansion of the crop suitability shift areas in Nicaragua. The communities' location also corresponds to the areas where Bouroncle et al. (2016) show a decrease of -0.7 to -0.3 of suitability change proportion for beans in 2030 and -0.2 to -0.1 of average suitability change proportion for the main crops cultivated in the region (see: Supplementary material n.6, from Bouroncle et al. 2016).

On the already implemented adaptation strategies

The fact that ANF was already intervening in some of the communities involved in this study does not allow an impartial analysis of which adaptation strategies have been autonomously implemented. The major focus on soil conservation techniques like crop rotation and cover crops suggests that farmers prefer to opt for inexpensive measures which do not require the adoption of new technology. Simple practices for soil conservation were included in the local adaptation strategies suggested by Smit & Skinner (2002). Diversification of crop varieties, reforestation and agroforestry do not appear to be common among the smallholder communities despite the potential of these measures to foster adaptation and productivity increase (Schroth, 2004). Irrigation and water harvesting are also of marginal diffusion, confirming the difficulties smallholder can face in implementing technology-based strategies as claimed by Lybbert & Sumner (2010). Low productivity and low income can explain the economic constraints the smallholders are facing and their preference for minimal or non-existent investments. In terms of nature conservation, the absence of disruptive activities like deforestation or slash-and-burn shows the positive approach undertaken by the smallholders. The frustration generally shown by the participants regarding the partial success of the implemented measures might be due to an overestimation of the potential benefits of the measures or to an incorrect implementation of them. Shiferaw et al. (2009) stress the tendency of smallholders to adopt different farming systems just in the case that the intervention can have an additional economic benefit which outweighs the initial cost. Voluntary implementation of adaptation strategies strongly depends on the short-term economic return, hampering the development of a vision which contemplates adaptation under a long-term perspective (Shiferaw et al. 2009). The fact that almost every smallholder implemented already one or more adaptation strategies proves that the interest around changing practices has grown in recent years.

On the barriers against the implementation of adaptation strategies

The interpretation of the results on the barriers against the implementation of adaptation strategies can be narrowed down to the following key points: the inexistence of mistrust and the prevalence of the economic barrier and lack of knowledge. These two main outcomes are clear both from the smallholder and the key informant perspective. Despite the lack of specific knowledge, it appears clear how the experienced impacts of climate change are sufficiently evident for the smallholders to generate urgency around adaptation. The social and cultural spheres as emphasized by Adger et al. (2009) seem not to be so relevant. The weak influence the respect of traditions barrier holds for the smallholders implies the low importance of individual or community values and the progressive mentality that smallholders show. The weight of the economic barrier reinforces the existence of the stressors already identified in the literature. The market pressure and the weak economic performance of the farming systems result in the difficulties that smallholders face in endeavouring investments for adaptation. To overcome this barrier, Hallegatte (2009) suggests supporting no-regret options. Essentially, measures that can ensure benefits independently of the advancement of climate change will be always considered a reliable investment for the smallholders (Hallegatte, 2009).

Confidence in investments can also be reinforced by the implementation of reversible strategies (Rounsevell et al. 1999). When the intervention does not present irreversible effects and can be easily withdrawn, it is likely that smallholders will be more positive about implementing it (Hallegatte, 2009).

The complexity of the lack of knowledge barrier emerges from the non-apparent connection between the level of education and the unawareness shown by the smallholders. While it would be simple to relate lack of knowledge with the education level, the findings show that this cause-effect relation is partially fallacious. Indeed, key informants clearly expressed how education is only part of the problem. A reason for that can stand in the specificity that education on climate change requires to be effective. Pruneau et al. (2003) demonstrated that the success of a pedagogical process aimed at raising awareness on climate change needs specific elements. Field trips, environmental actions and practical work can help accomplish a satisfactory level of information assimilation (Pruneau et al. 2003).

On the vulnerability analysis

The findings from the vulnerability analysis allow understanding not only how the impacts of climate change are affecting the communities but also to what extent the efforts made from the smallholders have been sufficient to cope with climate change. Firstly, the generally high value that sensitivity obtained in almost all different categories indicates that climate change already had a certain impact on natural resources. Water resources suffer climate change the most, probably as a result of the identified increase of the dry season's length, temperature increase and decrease of rainfall. The expressed damages to agricultural production appear evident observing the sensitivity of both agricultural and minor crops. In particular, the high scores of maize and beans, the staple food in the region, is alarming. Given that these two crops are both the base of the smallholders' diet and the main source of their income, their sensitivity calls for the urgency of implementing solutions for the maintenance of sufficiently high productivity levels. The values adaptive capacity score in every category indicates a generally positive trend regarding the success of the already implemented adaptation strategies. The score of water resources for adaptive capacity can be linked with the interventions made through irrigation, water harvesting and soil conservation practices. Likewise, irrigation and soil conservation can be the main reasons behind the high values that adaptive capacity obtained in the categories of agricultural and minor crops.

An interesting comparison of the findings on vulnerability can be made with the study of Baca et al. (2014). A sensitivity cluster analysis shows that Nicaragua's coffee growing families present a high level of sensitivity in 22% of the cases and a medium level of sensitivity in 61% of the cases (Baca et al. 2014). Although the variables in Baca et al. (2014) have been classified in a simpler manner, it is useful to notice how the predominance of a medium level of sensitivity lines up with the findings of this research. In fact, in this study the average sensitivity per category fluctuates between 2,62 of agricultural crops and 3,29 of water resources, where the medium possible average is exactly 3. Likewise, the adaptive capacity of growing coffee families reached lower values, with the 37% of the families belonging the lowest degree of adaptive capacity (Baca et al. 2014). According to the indicators used in the study, the low score for the adaptive capacity is due to the weak level of knowledge on farming systems, limited access to technology and scarce income diversification (Baca et al. 2014). This last analysis offers an additional perspective on the adaptive capacity of smallholder communities. It is likely that lack of knowledge together with weak economic incomes resulted in a partial or incorrect implementation of adaptation strategies, undermining their actual effectiveness.

On the most feasible adaptation strategies

The two most feasible adaptation strategies, education and biointensive agriculture, can complement each other. If biointensive agriculture represents a set of practices of which benefits can be directly experienced by the smallholders, education allows to structure and steer the development of an adaptation-based rural development in a long-term perspective. The relevance of the complementary nature of these two options is supported by the findings of Risbey et al. (1999). In agriculture, an optimal adaptive performance is achieved when the short-term decision-making is coupled with enduring structural planning (Risbey et al. 1999). Farm-level adaptation requires the implementation of measures which can offer benefits over different time scales (Risbey et al. 1999). Hence, the almost immediate benefits of biointensive agriculture can be coupled with the long-term effects of a climate-specific education plan.

Although restricted to only six options, the set of adaptation strategies that ANF proposes is comprehensive, as all the criteria of the research framework are fulfilled at least once and the three scales (plot, farm and landscape) are covered. Moreover, the options correspond to the most important adaptation strategies identified by Altieri & Koohafkan (2008) for smallholder communities, in particular crop diversity increase, agroforestry and soil conditions enhancement (part of biointensive agriculture) (Altieri & Koohafkan, 2008).

Limitations and recommendations for further research

The main limitations of this study are the sample size, the communication with the smallholders and the intrinsic shortcomings of the vulnerability analysis as specified by Ortega & Paz (2014). Moreover, the set of adaptation strategies which have been analysed was restricted to the only options ANF proposes.

Certainly, the limited possibility to move linked with the relatively short stay of the author in Nicaragua and the inflexible schedule of the workshops did not allow to achieve a greater sample size or to get in contact with different communities. Although the sufficient length of the workshop and the constant engagement with the participants permitted to respect the PRA principles of offsetting biases and facilitation, it is undeniable that visiting the communities in person would have increased the depth of the outsider-participant connection improving the quality of data collection. The author encountered some difficulties during the structured interviews in terms of the participant understanding of the questions and the topics discussed. The improvement of the interview structure after the first pilot workshop partially allowed to overcome this obstacle, although excessively simple language had to be used in a few occasions. The guide of Ortega &

Paz (2014) followed for the vulnerability analysis strictly focuses on natural resources vulnerability, cutting off important human, biological and socio-economic systems. Moreover, the quantification of both sensitivity and adaptive capacity is exclusively based on farmer perception and not supported by empirical data.

Further research should focus on a more precise and comprehensive vulnerability analysis without excluding the fundamental elements of PRA. For instance, Monterroso et al. (2014) propose a set of variables which include natural, social and financial capitals for agriculture vulnerability analysis at the municipality level. Still, the subjectivity in the indicators selection can hardly be avoided (Monterroso et al. 2014). With a larger availability of time and resources, the sample size and the study area can be increased and more specific information can be collected from the structured interviews. In retrospect, more attention could have been given to addressing the rationale behind the already implemented adaptation strategies and to better quantifying the climate change impacts on the yield loss. Finally, the selection of the most promising adaptation strategies can be realized through different approaches than the multi-criteria analysis. Lim et al. (2005) propose cost-benefit and cost-effectiveness analysis as equally useful methods in the agricultural adaptation strategies classification.

Policy recommendations

Adaptation-oriented research on agriculture is characterized by a high degree of complexity. In the particular case of smallholder communities, the co-existence of different and interconnected economic, social and environmental stressors can drastically undermine the success of adaptation strategies. The tendency of many studies to tie agricultural adaptation to only the physical or economic spheres while excluding the human element has to be overcome (Risbey et al. 1999). Instead, a more holistic approach grounded in farmer participation can give additional and valuable insights to support effective decision-making. Research has to consider the integration of interdisciplinary approaches and give greater emphasis to the way smallholders experience and respond to climate change. Instead of aiming at proposing universally applicable adaptation strategies, a major investment should be made in the development of local policies which support site-specific adaptation. Although a restricted focus can limit the number of communities which profit adaptation benefits, the multi-faceted character of local adaptation cannot be ignored in future adaptation policies. In the broader picture of governmental decision-making, agricultural policies for smallholder communities should be integrated with economic development projects, food security strategies and environmental policies.

ANF can take advantage of this long-term workshop project to enlarge its sphere of influence, engaging with more communities and testing the feasibility of a more diverse set of adaptation strategies. Moreover, ANF should ensure sufficient technical support to guide the smallholders in the strategies' realization. Considering the similarities of the Central American countries in terms of the predicted climate change impacts on agriculture (see: Eitzinger et al. 2012 and Bouroncle et al. 2016), it is without doubt that the methodology implemented in this research could be applied in the entire Dry Corridor region.

Conclusion

This research was designed to address the feasibility of climate change adaptation strategies for smallholder communities in the Dry Corridor of Nicaragua. The urgency to implement local adaptation strategies is hindered by the lack of interdisciplinary research which includes farmers engagement. Hence, this study was intended to cover the scarcely explored field of site-specific adaptation, proposing an innovative method which could help to integrate a bottom-up approach in the future climate change policies for agriculture. Moreover, the findings are meant to be of practical use for ANF.

The smallholder communities have similar characteristics in terms of farm dimension (average: 2.35 ha without extremes), self-consumption, self-organization and main cultivated crop (maize: 88.9 %; beans: 85.2%). Vice versa, the level of education largely varies from farmers having only received primary school education to having a university degree. The smallholders have a shared perception of the negative impacts of climate change, recognizing that the area is becoming drier as a result of both rainfall reduction and temperature increase. These climatic variations have caused yield loss, soil erosion and planting season shift. Interestingly, the majority of the smallholders already implemented one or more adaptation strategies, generally simple and with a low initial investment.

Regarding the barriers against the implementation of adaptation strategies, lack of knowledge and the economic barrier are the ones that stand out most. These two barriers score respectively 1.11 and 1.67. Moreover, the smallholders seem not to be limited by the tendency to follow the traditional agricultural practices. The lack of knowledge appears not to be related to the education level. The vulnerability analysis shows that the most vulnerable resources to climate change are superficial water resources, planted forest, grass pasture, maize and beans. The sensitivity per category always reaches high values, which confirms the experienced negative impacts of climate change on the farming system. Lower scores for the adaptive capacity confirmed the partial effectiveness of the already implemented adaptation strategies.

The last step of this research permitted identifying the most feasible adaptation strategies: biointensive agriculture and education. These two measures complement each other as they occur at different time-scales and they fulfil the largest spectrum of criteria, in particular of prioritized criteria. Hence, they can contribute to overcoming the two main identified barriers. While biointensive agriculture decreases the vulnerability of certain resources like water resources, agricultural crops and minor crops, education fosters farm-level innovation and the creation of a specific knowledge on climate change and adaptation.

Despite the limitations and the relatively small scope of this entire thesis, its contribution can be valuable for both the academic and policy discourse. The complexity of designing site-specific adaptation strategies for smallholder communities should not be underestimated. In fact, an adequate response to climate change has to consider that local adaptation requires the analysis of multiple stressors and a stronger engagement with the smallholders. Research should move towards the development of different strategies which merge top-down and bottom-up approaches while fostering participation. ANF is already moving in the right direction, empowering the farmers and steering the future of Nicaraguan rural development.

Sitography

ANF (2018) About ANF. Retrieved from http://anfnicaragua.org/ accessed on 07-02-2018.

ANF (2013) ANF's last report. Retrieved from http://anfnicaragua.org/what-we-do/agriculture/ accessed on 08-02-2018.

Charity Navigator (2018) website. Retrieved from https://www.charitynavigator.org/ accessed on 10-02-2018.

GrowBiointensive (2018). Retrieved from http://www.growbiointensive.org/ accessed on 02-06-2018.

INIDE (2015) Poverty results. Retrieved from http://www.inide.gob.ni/ accessed on 16-02-2018.

La Prensa website (2018). Retrieved from https://www.laprensa.com.ni/ accessed on 25-05-2018.

SistemaBio (2018). Retrieved from http://sistema.bio/que-es-biobolsa/ accessed on 21-05-2018.

The Guardian website (2018). Retrieved from https://www.theguardian.com/international accessed on 25-05-2018.

UNFCCC (2010). Glossary of Climate Change Acronyms" Archived 29 April 2010 at the Wayback Machine. Retrieved from https://unfccc.int/process-and-meetings/the-convention/glossary-of-climate-change-acronyms-and-terms accessed on 12-02-2018.

Vidiani (2018) Vidiani Nicaragua Map. Retrieved from http://www.vidiani.com/ accessed on 18-02-2018.

WorldBank (2018) Nicaragua profile. Retrieved from http://www.worldbank.org/en/country/nicaragua accessed on 04-06-2018.

Bibliography

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., ... & Wreford, A. (2009). Are there social limits to adaptation to climate change?. *Climatic change*, *93*(3-4), 335-354.

Aguilar, E., Peterson, T. C., Obando, P. R., Frutos, R., Retana, J. A., Solera, M., ... & Valle, V. E. (2005). Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003. *Journal of Geophysical Research: Atmospheres*, *110*(D23).

Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., ... & Edenhofer, O. (2014). IPCC fifth assessment synthesis report-climate change 2014 synthesis report.

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agronomy for Sustainable Development*, *32*(1), 1-13.

Altieri, M. A., & Koohafkan, P. (2008). Enduring farms: climate change, smallholders and traditional farming communities (Vol. 6). Penang: Third World Network (TWN).

Baca, M., Läderach, P., Haggar, J., Schroth, G., & Ovalle, O. (2014). An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. *PLoS One*, *9*(2), e88463.

Baca, M., Läderach, P., Haggar, J., Ovalle, O., Ocón, S., Gómez, L., & Zelaya, C. (2011). Vulnerabilidad y estrategias de adaptación al cambio climático en los medios de vida de las familias de Nicaragua. *Centro Internacional de Agricultura Tropical (CIAT), Managua, Nicaragua.*

Barenstein, J. E. D., & Leemann, E. (Eds.). (2012). *Post-Disaster Reconstruction and Change: Communities' Perspectives*. CRC Press.

BCN Banco Central de Nicaragua (2014). Cuadro de anuario estadístico macroeconómico (1960-2014). Obtenido de Estadística y Estudios: http://www.bcn.gob.ni/estadisticas/anuario_estadistico/ index.php.

Beddington, J. R., Asaduzzaman, M., Fernandez, A., Clark, M. E., Guillou, M., Jahn, M. M., ... & Scholes, R. J. (2012). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change.

Belder, P., Rohrbach, D., Twomlow, S. J., & Senzanje, A. (2007). Can drip irrigation improve the livelihoods of smallholders? Lessons learned from Zimbabwe: Global Theme on Agroecosystems Report no. 33.

Bendaña, G. (2012). Agua, agricultura y seguridad alimentaria en las zonas secas de Nicaragua. *ACF, FAO y ECHO, Managua, Nicaragua*.

Berdegué, J. A., & Fuentealba, R. (2011). Latin America: The state of smallholders in agriculture. In *IFAD conference on new directions for smallholder agriculture* (Vol. 24, p. 25).

Black, G. (1981). *Triumph of the People: The Sandinista Revolution in Nicaragua*. Black, George, Triumph of the people: the Sandinista revolution in Nicaragua. London: Zed Press Westport, Conn.: US distributor, Lawrence Hill & Co., 1981.

Borrvall, C., Ebenman, B., Jonsson, T., & Jonsson, T. (2000). Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters*, *3*(2), 131-136.

Bouroncle, C., Imbach, P., Läderach, P., Rodríguez, B., Medellín, C., & Fung, E. (2014). La agricultura de Nicaragua y el cambio climático:¿ Dónde están las prioridades para la adaptación?.

Bouroncle, C., Imbach, P., Rodríguez-Sánchez, B., Medellín, C., Martinez-Valle, A., & Läderach, P. (2016). Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies. *Climatic Change*, *141*(1), 123-137.

Burton, I., & Van Aalst, M. (2004). Look before you leap: a risk management approach for incorporating climate change adaptation into World Bank operations. World Bank Envirnoment Department.

Caldera, T., Palma, L., Penayo, U., & Kullgren, G. (2001). Psychological impact of the hurricane Mitch in Nicaragua in a one-year perspective. *Social psychiatry and psychiatric epidemiology*, *36*(3), 108-114.

Cartwright, A., Blignaut, J., De Wit, M., Goldberg, K., Mander, M., O'Donoghue, S., & Roberts, D. (2013). Economics of climate change adaptation at the local scale under conditions of uncertainty and resource constraints: the case of Durban, South Africa. *Environment and Urbanization*, *25*(1), 139-156.

Cetin, B., Yazgan, S., & Tipi, T. (2004). Economics of drip irrigation of olives in Turkey. *Agricultural Water Management*, *66*(2), 145-151.

Chai͡anov, A. V. (1986). AV Chayanov on the theory of peasant economy. Univ of Wisconsin Press.

Challinor, A. J., Slingo, J. M., Wheeler, T. R., Craufurd, P. Q., & Grimes, D. I. F. (2003). Toward a combined seasonal weather and crop productivity forecasting system: determination of the working spatial scale. *Journal of Applied Meteorology*, *42*(2), 175-192.

Chambers, R. (1997). Shortcut and participatory methods for gaining social information for projects. *Sustainable development: social organization, institutional arrangements and rural development*, *6*, 177-208.

Chambers, R. (2005). Rural appraisal: rapid, relaxed, participatory. Vikas Publishing House.

Chandra, G. (2010). Participatory rural appraisal. *Katiha, PK, Vaas, KK, Sharma, AP, Bhaumik, U. & Chandra Ganesh (Eds). Issues and tools for social science research in inland fisheries. Central Inland Fisheries Research Institute, Barrackpore, Kolkata, India. Bulletin*, (163), 286-302.

Charvériat, C. (2000). Natural disasters in Latin America and the Caribbean: An overview of risk.

Choptiany, J., Graub, B., Dixon, J., & Phillips, S. (2015). Self-evaluation and holistic assessment of climate resilience of farmers and pastoralists (SHARP). *FAO, Rome*, *155*.

Cohen, C., & Werker, E. D. (2008). The Political Economy of`Natural"Disasters. *Journal of Conflict Resolution*, *52*(6), 795-819.

Collins, K., & Ison, R. (2009). Living with environmental change: adaptation as social learning. *Environmental Policy and Governance*, *19*(6), 351-357.

Collinson, M. P. (Ed.). (2000). A history of farming systems research. CABI.

Conde, C., Ferrer, R., & Orozco, S. (2006). Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. *Atmósfera*, *19*(3), 181-194.

Corbetta, P. (2003). Social research: Theory, methods and techniques. Sage.

Cuadra, M., & Björklund, J. (2007). Assessment of economic and ecological carrying capacity of agricultural crops in Nicaragua. *Ecological indicators*, *7*(1), 133-149.

Dasberg, S., & Or, D. (2013). Drip irrigation. Springer Science & Business Media.

Davidson, J., & Lyth, A. (2012). Education for Climate Change Adaptation—Enhancing the Contemporary Relevance of Planning Education for a Range of Wicked Problems. *Journal for Education in the Built Environment*, *7*(2), 63-83.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global environmental change*, *19*(2), 248-255.

Dewar, R. E., & Wallis, J. R. (1999). Geographical patterning of interannual rainfall variability in the tropics and near tropics: An L-moments approach. *Journal of Climate*, *12*(12), 3457-3466.

Doody, O., & Noonan, M. (2013). Preparing and conducting interviews to collect data.

Droogers, P., & Aerts, J. (2005). Adaptation strategies to climate change and climate variability: a comparative study between seven contrasting river basins. *Physics and Chemistry of the Earth, Parts A/B/C*, *30*(6-7), 339-346.

Eakin, H., & Lemos, M. C. (2006). Adaptation and the state: Latin America and the challenge of capacity-building under globalization. *Global environmental change*, *16*(1), 7-18.

Earles, R., & Williams, P. (2005). Sustainable Agriculture an Introduction. ATTRA.

Eitzinger, A., Läderach, P., Rodriguez, B., Fisher, M., Rizo, L., & Ocon, S. (2012). TOR-Tortillas on the roaster: Central American maize-bean systems and the changing climate.

Fischer, G., Shah, M. M., & Van Velthuizen, H. T. (2002). Climate change and agricultural vulnerability.

Flesch, T. K., Desjardins, R. L., & Worth, D. (2011). Fugitive methane emissions from an agricultural biodigester. *Biomass and Bioenergy*, *35*(9), 3927-3935.

Freudenberger, K. S. (1999). Rapid rural appraisal (RRA) and participatory rural appraisal (PRA): a manual for CRS field workers and partners. *Baltimore: Catholic Relief Services*.

Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic change*, *75*(3), 301-329.

Garfí, M., Martí-Herrero, J., Garwood, A., & Ferrer, I. (2016). Household anaerobic digesters for biogas production in Latin America: A review. *Renewable and Sustainable Energy Reviews*, *60*, 599-614.

Garwood, A. (2010). Network for biodigesters in Latin America and the Caribbean: case studies and future recommendations. Inter-American Development Bank.

Giorgi, F. (2006). Climate change hot-spots. *Geophysical research letters*, *33*(8).

Goldberg, D., Gornat, B., & Rimon, D. (1976). Drip irrigation. Principles, design and agricultural practices. *Drip irrigation. Principles, design and agricultural practices.*

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change*, *15*(3), 199-213.

Guha-Sapir, D., Hargitt, D., & Hoyois, P. (2004). Thirty years of natural disasters 1974-2003: The numbers. Presses univ. de Louvain.

Hagan, K. (2012). Resumen del estudio tortillas en el comallos sistemas del maíz y frijol en centroamérica y el cambio climatico.

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global environmental change*, *19*(2), 240-247.

Harrell, M. C., & Bradley, M. A. (2009). Data collection methods. Semi-structured interviews and focus groups. Rand National Defense Research Inst santa monica ca.

Harvey, C., Alpízar, F., Chacón, M., & Madrigal, R. (2005). Assessing linkages between agriculture and biodiversity in Central America: Historical overview and future perspectives. The Nature Conservancy.

Harvey, C. A., Chacón, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., ... & Clement, C. (2014). Climate‐smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters*, *7*(2), 77-90.

Harvey-Jordan, S., & Long, S. (2001). The process and the pitfalls of semi-structured interviews. *Community Practitioner*, *74*(6), 219.

Hazell, P., Anderson, J., Balzer, N., Hastrup Clemmensen, A., Hess, U., & Rispoli, F. (2010). *The potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods*. World Food Programme (WFP).

Herring, H., & Herring, H. B. (1968). History of Latin America from the Beginnings to the Present.

Holden, S. T., Shiferaw, B., & Wik, M. (1998). Poverty, market imperfections and time preferences: of relevance for environmental policy?. *Environment and Development Economics*, *3*(1), 105-130.

Holloway, I., & Galvin, K. (2016). *Qualitative research in nursing and healthcare*. John Wiley & Sons.

Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the national academy of sciences*, *104*(50), 19691-19696.

Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the total environment*, *409*(19), 3578-3594.

Hufschmidt, G. (2011). A comparative analysis of several vulnerability concepts. *Natural hazards*, *58*(2), 621-643.

Imbach Bartol, P. A., Molina, L., Locatelli, B., Roupsard, O., Mahé, G., Neilson, R., ... & Clais, P. (2012). Modelling Potential Equilibrium States of Vegetation and Terrestrial Water Cycle of Mesoamerica under Climate Change Scenarios.

IPCC, Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects*. Cambridge University Press.

Jaspers, A. M. J., ter Maat, H. W., Supit, I., & Kondaiah, S. A. R. (2012). Climate proofing bio-intensive rainfed farming systems, Accion Fraterna Ecology Centre Anantapur, India. Alterra.

Jeavons, J. C. (2001). Biointensive sustainable mini-farming: II. Perspective, principles, techniques and history. *Journal of Sustainable Agriculture*, *19*(2), 65-76.

Jiménez, A. J. (2004). Análisis de la pobreza y la seguridad alimentaria nutricional en Nicaragua. Instituto Nacional de Estadisticas y Censos (INEC), Managua (Nicaragua).

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry systems*, *76*(1), 1-10.

Joyce, T. A. (2013). Central American and West Indian archaeology: being an introduction to the archaeology of the states of Nicaragua, Costa Rica, Panama and the West Indies. Cambridge University Press.

Karmalkar, A. V., Bradley, R. S., & Diaz, H. F. (2011). Climate change in Central America and Mexico: regional climate model validation and climate change projections. *Climate dynamics*, *37*(3-4), 605.

Keen, B., & Haynes, K. (2012). A history of Latin America. Cengage Learning.

Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and Facilitating adaptation. *Climatic change*, *47*(4), 325-352.

Kinloch Tijerino, F. (2008). Historia de Nicaragua. Instituto de Historia de Nicaragua y Centroamerica de la Universidad Centroamericana, Managua (Nicaragua).

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food policy*, *32*(1), 25-48.

Kreft, S., Eckstein, D., Junghans, L., Kerestan, C., & Hagen, U. (2014). Global climate risk index 2015: who suffers most From extreme weather events? weather-related loss events in 2013 and 1994 to 2013.

Laukkonen, J., Blanco, P. K., Lenhart, J., Keiner, M., Cavric, B., & Kinuthia-Njenga, C. (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat international*, *33*(3), 287-292.

Lavergne, S., Mouquet, N., Thuiller, W., & Ronce, O. (2010). Biodiversity and climate change: integrating evolutionary and ecological responses of species and communities. *Annual review of ecology, evolution, and systematics*, *41*, 321-350.

Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E., & Huq, S. (2005). Adaptation policy frameworks for climate change: developing strategies, policies and measures.

Lybbert, T., & Sumner, D. (2010). Agricultural technologies for climate change mitigation and adaptation in developing countries: policy options for innovation and technology diffusion.

Magrin, G. (2007). Latin america. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 581-615.

Mani, A., & Suresh, C. P. (2018) Climate Resilient Fruit Crops–Possible Solution to Ensure Nutritional Security in Changing Climate Scenario. *Training Manual*, 51.

Marín, Y., Defeltsen, G., Fernández, M., Aguilar, A., & Rivas, R. (2007). La política y legislación forestal nicaragüense: implicaciones para el fomento y aprovechamiento arbóreo en fincas ganaderas. *Encuentro*, (77), 29.

Marshall, G. R., Patrick, I. W., Muktasam, A., & Ambarawati, I. G. A. A. (2006). Alleviating poverty by linking smallholders with agribusiness: Roles of social capital and common property. In *11th Biennial conference of the international association for the study of common property, Ubud, Bali, Indonesia* (Vol. 19, p. 23).

Marshall, N. A., Marshall, P. A., Tamelander, J., Obura, D., Malleret-King, D., & Cinner, J. E. (2010). *A framework for social adaptation to climate change: sustaining tropical coastal communities [sic] and industries*. IUCN.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (Eds.). (2001). Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 2). Cambridge University Press.

McCracken, J. A., Pretty, J. N., & Conway, G. R. (1988). An introduction to rapid rural appraisal for agricultural development.

McIntosh, M. J., & Morse, J. M. (2015). Situating and constructing diversity in semi-structured interviews. *Global qualitative nursing research*, *2*, 2333393615597674.

Mendelsohn, R. O., & Seo, S. N. (2007). Changing farm types and irrigation as an adaptation to climate change in Latin American agriculture.

Mendoza, R., Dávila, O., Fonseca, F., Cheaz, J., & RIMISP. (2012). Modelo de Adaptación al Cambio Climático a través de la Reconversión Productiva y transformación territorial. Proyecto CAMBio en Nicaragua. *Alianzas para el empoderamiento económico. Santiago*.

Mendoza, G. A., & Prabhu, R. (2005). Combining participatory modeling and multi-criteria analysis for community-based forest management. *Forest Ecology and Management*, *207*(1-2), 145-156.

Mercer, D. E., & Miller, R. P. (1998). Socioeconomic research in agroforestry: progress, prospects, priorities. In *Directions in Tropical Agroforestry Research* (pp. 177-193). Springer, Dordrecht.

Mertz, O., Halsnæs, K., Olesen, J. E., & Rasmussen, K. (2009). Adaptation to climate change in developing countries. *Environmental management*, *43*(5), 743-752.

Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L. (2007). Climate Change 2007: Mitigation (No. C048. 060). Intergovernmental Panel on Climate Change.

Monterroso, A., Conde, C., Gay, C., Gómez, D., & López, J. (2014). Two methods to assess vulnerability to climate change in the Mexican agricultural sector. *Mitigation and Adaptation Strategies for Global Change*, *19*(4), 445-461.

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, *104*(50), 19680-19685.

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the national academy of sciences*, 201007887.

Mukherjee, A., & Chambers, R. (2004). Participatory rural appraisal: methods and applications in rural planning: essays in honour of Robert Chambers (Vol. 5). Concept Publishing Company.

Murphy, P. G., Lugo, A. E., Bullock, S. H., Mooney, H. A., & Medina, E. (1995). Seasonally dry tropical forests. *Seasonally dry tropical forests*.

Narayanamoorthy, A. (1997). Economic viability of drip irrigation: An empirical analysis from Maharashtra. *Indian Journal of Agricultural Economics*, *52*(4), 728.

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., ... & Magalhaes, M. (2009). *Climate change: Impact on agriculture and costs of adaptation* (Vol. 21). Intl Food Policy Res Inst.

Netting, R. M. (1993). Smallholders, householders: farm families and the ecology of intensive, sustainable agriculture. Stanford University Press.

Newson, L. (1992). Variaciones regionales en el impacto del dominio colonial español en las poblaciones indígenas de Honduras y Nicaragua. *Mesoamérica*, *13*(24), 297-312.

Nowak, A., Corner-Dolloff, C., Lizarazo, M., Jarvis, A., Kray, H., & Arce, C. (2015). Climate-Smart Agriculture in Nicaragua.

Ortega L; Paz L; (2014). Manual para la formulación de planes prediales de adaptación a la variabilidad climática 49 p. Colombia.

Pacey, A., & Thrupp, L. A. (1989). Farmer first: Farmer innovation and agricultural research. Intermediate Technology Publications.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). IPCC.

Padgham, J. (2009). Agricultural development under a changing climate: opportunities and challenges for adaptation. World Bank.

Palmer, W. C. (1965). Meteorological drought. Research Paper No. 45. Washington, DC: US Department of Commerce. *Weather Bureau*, 59.

Parry, I. P. C. C., & OF, P. (2007). PJ and CE Hanson, Eds., Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Pattanayak, S. K., & Mercer, D. E. (2002). Indexing soil conservation: farmer perceptions of agroforestry benefits. *Journal of Sustainable Forestry*, *15*(2), 63-85.

Pimienta-Barrios, E., Nobel, P. S., Robles-Murguía, C., Mendez-Moran, L., Pimienta-Barrios, E., & Yepez-Gonzalez, E. (1997). Ethnobotany, productivity, and ecophysiology of pitaya (Stenocereus queretaroensis). *Journal of the Professional Association for Cactus Development*, *2*, 29-47.

Preston, T. R., & Rodríguez, L. (2002). Low-cost biodigesters as the epicenter of ecological farming systems. In *Proceedings biodigester workshop*.

Price, C. (1995). Economic evaluation of financial and non-financial costs and benefits in agroforestry development and the value of sustainability. In *Agroforestry: Science, Policy and Practice* (pp. 75-86). Springer, Dordrecht.

Pruneau, D., Gravel, H., Bourque, W., & Langis, J. (2003). Experimentation with a socio-constructivist process for climate change education. *Environmental Education Research*, *9*(4), 429-446.

Ramírez, D., Ordaz, J. L., Mora, J., Acosta, A., & Serna, B. (2010). Nicaragua: efectos del cambio climático sobre la agricultura. CEPAL. CCAD. DFID..

Ravera, F., Tarrasón, D., & Simelton, E. (2011). Envisioning adaptive strategies to change: participatory scenarios for agropastoral semiarid systems in Nicaragua. *Ecology and Society*, *16*(1).

Ravnborg, H. M. (2008). Organising to protect: Protecting landscapes and livelihoods in the Nicaraguan hillsides. *Conservation and Society*, *6*(4), 283.

Reid, H., & Huq, S. (2007). Community-based adaptation: A vital approach to the threat climate change poses to the poor. *International Institute for Environment and Development (IIED). Briefing Paper, London: IIED*.

Reidsma, P., Ewert, F., Lansink, A. O., & Leemans, R. (2010). Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. *European journal of agronomy*, *32*(1), 91-102.

Risbey, J., Kandlikar, M., Dowlatabadi, H., & Graetz, D. (1999). Scale, context, and decision making in agricultural adaptation to climate variability and change. *Mitigation and adaptation strategies for global change*, *4*(2), 137-165.

Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., ... & Qiang, Z. (2010). Managing water in rainfed agriculture—The need for a paradigm shift. *Agricultural Water Management*, *97*(4), 543-550.

Rojas Blanco, A. V. (2006). Local initiatives and adaptation to climate change. *Disasters*, *30*(1), 140-147.

Ropelewski, C. F., & Halpert, M. S. (1987). Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly weather review*, *115*(8), 1606-1626.

Rounsevell, M. D. A., Evans, S. P., & Bullock, P. (1999). Climate change and agricultural soils: impacts and adaptation. *Climatic Change*, *43*(4), 683-709.

Salkeld, D. J., Padgett, K. A., & Jones, J. H. (2013). A meta-analysis suggesting that the relationship between biodiversity and risk of zoonotic pathogen transmission is idiosyncratic. *Ecology letters*, *16*(5), 679-686.

Salmerón, F., & Valverde, O. (2016). Agricultura sostenible para enfrentar los efectos del Cambio Climático en Nicaragua.9.

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19703-19708.

Schoeneberger, M., Bentrup, G., De Gooijer, H., Soolanayakanahally, R., Sauer, T., Brandle, J., ... & Current, D. (2012). Branching out: Agroforestry as a climate change mitigation and adaptation tool for agriculture. *Journal of Soil and Water Conservation*, *67*(5), 128A-136A.

Schroth, G. (Ed.), (2004). Agroforestry and biodiversity conservation in tropical landscapes. Island Press.

Shah, T., & Keller, J. (2002). Micro-irrigation and the poor: A marketing challenge in smallholder irrigation development. In *Private irrigation in sub-Saharan Africa: Regional seminar on private sector participation and irrigation expansion in sub-Saharan Africa, 22-26 October 2001,* Accra, Ghana (pp. 165-184).

Shiferaw, B. A., Okello, J., & Reddy, R. V. (2009). Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, development and sustainability*, *11*(3), 601-619.

Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, *8*(9), 9.

Smit, B., & Skinner, M. W. (2002). Adaptation options in agriculture to climate change: a typology. *Mitigation and adaptation strategies for global change*, *7*(1), 85-114.

Smithers, J., & Blay-Palmer, A. (2001). Technology innovation as a strategy for climate adaptation in agriculture. *Applied Geography*, *21*(2), 175-197.

Solomon, S., Qin, D., Manning, M., Averyt, K., & Marquis, M. (Eds.). (2007). Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC (Vol. 4). Cambridge university press.

Tarrasón, D., Urrutia, J. T., Ravera, F., Herrera, E., Andrés, P., & Espelta, J. M. (2010). Conservation status of tropical dry forest remnants in Nicaragua: Do ecological indicators and social perception tally?. *Biodiversity and Conservation*, *19*(3), 813-827.

Toman, M. (2006). Values in the economics of climate change. *Environmental Values*, *15*(3), 365-379.

Tscharntke, T., Clough, Y., Bhagwat, S. A., Buchori, D., Faust, H., Hertel, D., ... & Scherber, C. (2011). Multifunctional shade-tree management in tropical agroforestry landscapes–a review. *Journal of Applied Ecology*, *48*(3), 619-629.

Turner, N., Gregory, R., Brooks, C., Failing, L., & Satterfield, T. (2008). From invisibility to transparency: identifying the implications. *Ecology and society*, *13*(2).

UNESCO, United Nations Educational, Scientific and Cultural Organization (2015). Not just hot air. Putting climate change education into practice.

Vallecillo, R. (2012). La quema: destruye el suelo y pone en riesgo la vida. *Servicio de Información Mesoamericano sobre Agricultura Sostenible, Managua (Nicaragua).*

Van Aalst, M. K., Cannon, T., & Burton, I. (2008). Community level adaptation to climate change: the potential role of participatory community risk assessment. *Global environmental change*, *18*(1), 165-179.

Van den Berg, M., & Burger, K. (2008). Household consumption and natural disasters: The case of Hurricane Mitch in Nicaragua. In *12th EAAE Congress 'People, Food and Environments: Global Trends and European Strategies', Gent, Belgium*.

Van der Zee Arias, A., Meyrat, A., & Van der Zee, J. (2012). *Estudio de caracterizacion del Corredor Seco Centroamericano* (No. 630.2515/V217e). FAO.

Verchot, L. V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., ... & Palm, C. (2007). Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and adaptation strategies for global change*, *12*(5), 901-918.

Vermeulen, S. J., Aggarwal, P. K., Ainslie, A., Angelone, C., Campbell, B. M., Challinor, A. J., ... & Lau, C. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136-144.

Vignola, R., Harvey, C. A., Bautista-Solis, P., Avelino, J., Rapidel, B., Donatti, C., & Martinez, R. (2015). Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. *Agriculture, Ecosystems & Environment*, *211*, 126-132.

Villanueva, C., Ibrahim, M., Casasola, F., Ríos, N., & Sepúlveda, C. (2009). Sistemas silvopastoriles: una herramienta para la adaptación al cambio climático de las fincas ganaderas en América Central. *Políticas y sistemas de incentivos para el fomento y adopción de buenas prácticas agrícolas*, *103*.

Wamsler, C., Brink, E., & Rentala, O. (2012). Climate change, adaptation, and formal education: the role of schooling for increasing societies' adaptive capacities in El Salvador and Brazil. *Ecology and Society*, *17*(2).

Weber, E. U. (1997). Perception and expectation of climate change. *Psychological perspectives to environmental and ethical issues in management*, 314-341.

Weber, E. U. (2010). What shapes perceptions of climate change?. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(3), 332-342.

Wells, N., Goddard, S., & Hayes, M. J. (2004). A self-calibrating Palmer drought severity index. *Journal of Climate*, *17*(12), 2335-2351.

Williams, D. G., Hultine, K. R., & Dettman, D. L. (2014). Functional trade-offs in succulent stems predict responses to climate change in columnar cacti. *Journal of experimental botany*, *65*(13), 3405-3413.

Wolf, J., & Moser, S. C. (2011). Individual understandings, perceptions, and engagement with climate change: insights from in-depth studies across the world. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(4), 547-569.

Wright, H., Vermeulen, S., Laganda, G., Olupot, M., Ampaire, E., & Jat, M. L. (2014). Farmers, food and climate change: ensuring community-based adaptation is mainstreamed into agricultural programmes. *Climate and development*, *6*(4), 318-328.

Yates, D. N., Kittel, T. G., & Cannon, R. F. (2000). Comparing the correlative Holdridge model to mechanistic biogeographical models for assessing vegetation distribution response to climatic change. *Climatic Change*, *44*(1-2), 59-87.

Yohe, G., & Tol, R. S. (2002). Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. *Global environmental change*, *12*(1), 25-40.

Young, A. (1997). Agroforestry for soil management (No. Ed. 2). CAB international.

Zimmerman, T. W., Montilla, C., Harris, H., Gordon, J., & Smart, R. (2013) Evaluation of 25 Pitaya Varieties in the United States Virgin Islands. *Agricultural Experiment Station*, 20.

Annexes

Annex I: topic list of the structured interview with the smallholders

- Gender:
- Name:
- Age:
- Community:
- Education:
- Previous jobs:
- Dimension of the farm:
- Soil condition of the farm:
- Decision-making in the farm management:
- Main cultivated crops in the farm:
- Extra activities for income generation:
- Production level (self-consumption or product selling):
- Already implemented adaptation strategies:
- Main barriers which impede to implement more adaptation strategies:

Economic	Lack of knowledge	Mistrust on necessity	Bureaucratic	Respect of traditions

(0=not influent, 1= quite influent, 2= very influent)

Annex II: Vulnerability questionnaire

For the sensitivity analysis:

Nombre:	**Valoración de la sensibilidad**				
Categoría	Variable	**Fenómenos Naturales**			**TOTALES**
Recursos hídricos	Fuentes superficiales (ríos, lagos..)				
	Fuentes subterránea (fuentes, pozos..)				
Cobertura Arbórea	Áreas boscosas				
	Árboles en línea				
Ganadería	Pastos con arboles				
	Pastos de corte				
Cultivos	Maíz				
	Frijol				
	Arroz				
	Café				
	Cacao				
Patio	Frutales				
	Hortalizas				
	Enramadas				
	Especies menores				

Donde los valores son:

1 = el recurso no es afectado por el fenómeno.
2 = el recurso es poco afectado por el fenómeno.
3 = el recurso es muy afectado por el fenómeno.

For the adaptive capacity analysis:

Nombre:	**Valoración de la capacidad de adaptación**				**TOTALES**
Categoría	Variable	**Fenómenos Naturales**			
Recursos hídricos	Fuentes superficiales (rios, lagos..)				
	Fuentes subterránea (fuentes, pozos..)				
Cobertura Arbórea	Áreas boscosas				
	Árboles en línea				
Ganadería	Pastos con arboles				
	Pastos de corte				
Cultivos	Maíz				
	Frijol				
	Arroz				
	Café				
	Cacao				
Patio	Frutales				
	Hortalizas				
	Enramadas				
	Especies menores				

Donde los valores son:

1 = no se han implementado actividades de adaptación para evitar los efectos negativos de los fenómenos naturales.
2 = se han implementado actividades de adaptación pero no son suficientes para disminuir los efectos negativos de los fenómenos naturales.
3 = se han implementado suficientes actividades de adaptación para evitar los efectos negativos de los fenómenos naturales.

English version:

Name:						
Category	Variable	Natural events			TOTAL
Water resources	Superficial water resources				
	Underground water resources				
Forest	Natural forest				
	Planted forest				
Livestock	Forested pasture				
	Grass pasture				
Agricultural crops	Maize				
	Beans				
	Rice				
	Coffee				
	Cacao				
Minor crops	Fruit				
	Vegetables				
	Undergrowth				
	Other plants				