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Understanding microenvironments and the potential of traditional farming systems in a changing climate in Mexico and Belize

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ABSTRACT

In Latin America and the Caribbean, climate change impacts have been particularly strongly felt by small-scale farmers who still practice farming that is highly dependent on rainfall and on traditional management. In the Yucatan Peninsula (Southern Mexico, Belize, and Northern Guatemala), these effects have particularly impacted Maya indigenous communities (Maya Yucatec) that practice traditional rain-fed agriculture. One of the traditional farming systems that continues to be practiced by the Maya people for millennia but has also been changing from its ancient origin is the Maya *milpa* or Kool (as referred to in Maya language). The Maya *milpa* is a polyculture system planted with a wide variety of plants (mainly maize, beans, and squash), managed in many ways under a biocultural approach, and characterized for supporting local food systems, social structures and the use of indigenous knowledge.

Milpa has been of great scientific interest, not only because it has remained present in the livelihoods, culture, and local economy of Maya communities for centuries, providing income, food security, and cultural identity, but due to its vulnerability to extreme weather events such as droughts and hurricanes. Climatic variability, its impact on *milpa*, and how local societies adapt to climatic disturbances in this region has been explored by different authors. However, few studies have compared transnational adaptation responses within the same ethnic group practicing *milpa* and the role of indigenous knowledge in these adaptation strategies.

This thesis investigates what aspects Maya Yucatec farmers prioritise when building resilience to climate change and how they use and adapt indigenous and other knowledge systems to develop this resilience. The research uses a convergent mixed methods approach to document, assess and compare similarities and differences in views, experiences and capacities within the Maya Yucatec people to explore the adaptation processes in traditional *milpa* and describes and analyses changes in local environmental conditions impacting *milpa* management. This study was conducted by drawing on data collected from eight case studies and 35 surveys with Maya Yucatec farmers in six communities in Mexico and Belize and empirical data on local weather and soil conditions.

The results show that although sharing similar ethnicity, cultural background, environmental conditions, and livelihood patterns, Maya Yucatec farmers in the studied

communities have remarkably different individual relationships with the *milpa* system. This farmer-*milpa* relationship has been shaped by historical processes and influenced by site-specific factors like social networks, interlinked with external factors. This has indirectly shaped *milpa* management and consequently their farming priorities, their adaptive capacity and their use of indigenous knowledge.

Although climate stressors have influenced changes in *milpa*, there are other factors that have driven changes in *milpa* and vary across countries. In Mexico, changes have been shaped by social and cultural elements and networks, while in Belize key drivers were market demands and business trends.

Within the past 30 years (1991-2021) different variable long-term monthly average precipitation and average temperature have been observed across three of the six communities studied. In terms of soil attributes, pH presented the lowest variability amongst the studied plots while phosphate, potassium, and particle size distribution showed the highest variability. Maya Yucatec farmers reported several, frequent, perceptible and situated changes in climate but variable precipitation and temperature appeared to be the most commonly perceived in both countries, which in most cases aligned with empirical data.

When adapting and building resilience to climate change, Maya Yucatec farmers in Mexico and Belize use a combination of indigenous and modern knowledge. The use of indigenous knowledge remains active but can vary significantly depending on farmer's individual priorities and thus its capacity to be regenerated, renewed, and adapted is different and autonomous. Similarly, this research found that Maya Yucatec farmers are using epistemological pluralistic approaches and reshaping indigenous and modern knowledges into an indigenous adaptive knowledge as a coping mechanism.

The adaptation strategies implemented by Maya Yucatec farmers are heterogenous across both countries, but so is the knowledge embedded in these strategies. Changing or adjusting planting times, is perceived by farmers as the most reliable. Adaptation strategies are largely based on farmer's individual knowledge and experiential learning in Mexico and on knowledge from external sources in Belize. Given that knowledge systems are a fundamental aspect of *milpa* management and of Maya Yucatec social identity, it can be inferred that climate change is also impacting social and cultural dynamics and driving cultural adaptation.

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List of Abbreviations

AD-FK	Adaptation driven by farmers' knowledge/experiential learning
AD-GNG	Adaptation driven by government or non-government organizations
AIK	Adaptive indigenous knowledge
ADAS	Agricultural Development and Advisory Service
ANOVA	Analysis of Variance
BZ	Belize
BZD	Belize Dollars
CARDI	Caribbean Agricultural Research and Development Institute
CICY	Yucatan Scientific Research Center
CIMMYT	International Maize and Wheat Improvement Center
CCCCC	Caribbean community Climate Change Centre
COMEGEI	Mexican Committee for Emissions Reduction and Capture Projects
CONABIO	Commission for the Knowledge and Use of Biodiversity
CONAFOR	National Forest Commission
COVID-19	Coronavirus disease
CV	Coefficient of variation
DoE	Department of Environment
FAO	Food and Agriculture Organisation
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GFRAS	Global Forum for Rural Advisory Services
GoB	Government of Belize
IK	Indigenous knowledge
INEGI	National Institute of Statistics and Geography
IPECC	Special Climate change Program
IPCC	Intergovernmental Panel on Climate change
K	Potassium
LDN	Land Degradation Neutrality
LDNTSP	Land Degradation Neutrality Target Setting Programme
LGCC	General Law in Climate Change

LK/LEK	Local knowledge
LOI	Loss on Ignition
MX	Mexico
MoA	Ministry of Agriculture
NAFTA	North American Free Trade Agreement
NGO	Non-government organisation
NO ₃ -N	Nitrate Nitrogen
NOM	Norma Oficial Mexicana
OM	Organic Matter
P	Phosphorus/Phosphate
PLECCA	Special Climate change Program for Agriculture
REDD+	Reducing emissions from deforestation and forest degradation
SEMARNAT	Secretariat of Environment and Natural Resources
SIDS	Small Island Developing States
SOC	Soil Organic Carbon
SSLRC	Soil Survey and Land Research Centre
SIB	Statistical Institute of Belize
SSLRC	Soil Survey and Land Research Centre
SPI	Standard precipitation index
TK/TEK	Traditional Ecological Knowledge
UB	University of Belize
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
WRB	World Reference Base

CHAPTER 1 Introduction

1.1 Overview

Ecosystems across the globe have always been impacted by extreme weather events like floods, hurricanes and droughts, disrupting not only physical environments but also social systems. These disruptions of both social and natural systems have led humans to try to understand such extreme events to learn coping strategies (Folke et al., 2002). As a result of this evolving understanding, a capacity of adaptation has been developed by societies using strategies that have been transmitted across time (Biggs et al., 2015; Colding et al., 2001; Nakashima et al., 2012). In traditional societies, these adaptation strategies are diversified and grounded in social elements, like local or indigenous knowledge and traditional practices, and insight around many elements of nature like weather and soil have been used and passed down over generations (Berkes et al., 2000).

The knowledge of traditional and indigenous communities (termed for the purpose of this research as indigenous knowledge, IK) has played a significant role in understanding the relationship between humans and their environment (Berkes, 1999). IK has been studied across many fields such as anthropology, ethnography, ecology, and botany, leading to a worldwide recognition of the value indigenous knowledge has as an integrated system of knowledge (Inglis, 1993) and the impacts it can have on modern globalised world.

The use of IK, how it changes and the role it plays in resilience to climate change has received little attention in the academic literature. Indeed, researchers have pointed out the need for additional studies to situate indigenous knowledge adaptation in the context of climate change (e.g. Taylor et al., 2023). This is particularly relevant in the context of Latin America and the Caribbean as 826 different indigenous groups live in the region accounting for a total of 58 million people (ECLAC & FILAC, 2020; Harvey et al., 2018).

Within Latin America, Mexico is considered to have the largest and most diverse indigenous populations. According to the latest census from Mexico's National Institute of Statistics and Geography (INEGI) there are a total of 68 indigenous groups, equivalent to 19.4% of the country's total population (23.2 million people; INEGI 2020). Within Central America, despite being a small country, Belize is considered the most culturally diverse nation of mixed ancestry, most of them descendants of immigrants which is

deeply connected with the history of the country. Despite being considered ethnically heterogeneous, there are only two indigenous groups accounting for 17% of Belize's population, the Maya people at 11.3% (including Maya Q'eqchi, Maya Mopan and Maya Yucatec) and the Garifuna, descendants of African slaves at 6.1% (Statistical Institute of Belize; 2013). Overall, in Mexico and Central America there is a total of 28 Maya ethnic groups, and Mexico and Belize share the largest group of Maya peoples: the Yucatec Maya.

Given the ethnic diversity present in the region, there is a need to expand the understanding of the significance of indigenous knowledge, particularly through deep examination of the epistemology and usage by modern indigenous societies and how it has been adapted amidst global challenges like climate change. Understanding how IK adaptation occurs and is mediated by cultural diversity, as well as its impacts on resilience, especially regarding local livelihoods such as agriculture is crucial for climate science and local policy development. Despite this relevance, how climate change is influencing and reshaping the ways knowledge is produced, distributed, and applied continues to be underexplored and several gaps in the literature remain.

1.2. Importance of indigenous knowledge systems in building resilience to challenges

One of the valuable uses of IK in modern studies is related to understanding how resilience to disturbances and uncertainties is built in social-ecological systems through time and under different stressors. This has been of great significance when studying agricultural systems and the impacts of climatic variability, as farmers are considered one of the most vulnerable groups to climate change effects (Cohn et al., 2017; Donatti et al., 2019; Morton, 2007), and are custodians of knowledge originating before the advent of modern conservation and science (UNEP, 2020).

Studies of traditional agricultural systems across the globe have provided a better understanding of the effects of climate change on terrestrial ecosystems including the knowledge and experience acquired by small-scale farmers around local climatic conditions and their crops, their vulnerability to extreme weather events, and the capacity of adaptation across time (Harvey et al., 2018; Ingty, 2017; Mardero et al., 2015; Metcalfe et al., 2020; Schmook et al., 2013; Viguera et al., 2019). The outcomes of these

studies are of great significance because of the high impacts that agricultural systems have on livelihoods and food security (Eitzinger et al., 2014).

Researchers have highlighted the importance of prioritising and better understanding the role that IK plays in agricultural systems, the importance of merging it with scientific knowledge to face global challenges such as food insecurity, and its potential to improve policy decision making that is beneficial for farmers in their local contexts (Alexander et al., 2011; Gómez-Baggethun & Reyes-García, 2013; Johns et al., 2013; Phungpracha et al., 2016; Tanner et al., 2015).

Considering that for many indigenous peoples rainfed agriculture has historically been both an agroecological system and a cultural repository (Woodley et al., 2008), intimately connected to their identity (ECLAC & FILAC, 2020), recognising the value of these knowledge systems should be prioritized when studying climate change adaptation and resilience in these communities.

1.3 Recognising the value of knowledge systems: interlinking cultural and epistemological diversity

Despite the wide recognition of the world's cultural diversity, the relevance of the epistemological diversity embedded in the different non-dominant social groups across the globe is often dismissed (Santos, 2007; Smith, 2021). Several authors have argued that there has been an epistemological privilege assigned to modern science, or Western science, over other non-scientific forms of knowledge (Foucault & Sheridan, 1972; Quijano, 2000; Santos, 2007) setting it as “the hegemonic knowledge of the globalized world” (Bennett, 2024, p. 2). This form of suppression has not only been towards knowledge, but also towards “social groups whose social practices are informed by such knowledges” (Santos, 2007, p. 19) in what it has been called *epistemicide* (de Sousa Santos, 2016; Santos, 2007; Tom et al., 2019).

Many scholars have discussed the importance of integrating non-scientific knowledges into scientific knowledge, however this approach has been criticised since it doesn't really remove the epistemological privilege of modern science (Tom et al., 2019). As a result, some scholars have proposed alternative epistemologies that remove the privilege of more dominant knowledges (e.g. scientific knowledge) and instead place them “in the context of diversity of knowledges existing in contemporary societies” (Santos, 2007, p.

20) translated into an ecology of knowledges (de Sousa Santos, 2016) or advocating for multinaturalist knowledges (Viveiros De Castro, 2004).

Ecology of knowledges and multinaturalist knowledges approaches recognise and respect the multiple and diverse ways of understanding the natural world, particularly through the lenses of different societies or cultural groups. They acknowledge that understanding is not fixed or singular, but instead plurally perceived and understood depending on the cultural, historical and ecological contexts of the people involved (Santos, 2007; Viveiros De Castro, 2004). These approaches advocate for epistemological openness when trying to understand the natural world and recognition of different kinds of knowledge “aimed at maximizing their perspective contributions to build a more democratic and just society and at decolonizing knowledge and power” (Santos, 2007, p. 20).

These ideas have been adopted by other scholars like Bennett (2024) who argues that there is a need to reshape the way we think about the world by finding ways to break down long standing division between knowledges. In doing this, the concept of inter-epistemic translation has emerged to explain that knowledge evolves when new ideas and approaches build upon existing ones which can help to bridge the cognitive gaps that exist within the Western academic tradition and globally. Inter-epistemic translation encourages connections between seemingly unrelated fields of knowledge and fosters collaboration among researchers from diverse disciplines, all working together toward a shared objective (Bennett, 2024).

Inter-epistemic approaches require a critical review and reflection on specific views, aspects and practices from traditional and indigenous societies, and how modern science can be situated within this and co-exist to achieve epistemological diversity. It also requires intercultural understanding to transform current “science” into frameworks driven by different worldviews that can be applied to specific challenges embedded in environmental, sociocultural, and spiritual perceptions of life and nature (Botha, 2012; Sjöström & Eilks, 2020).

This inter-epistemic approach is particularly relevant when studying the impact of climate change on traditional agriculture as often two crucial knowledges, indigenous and scientific, play an important role in understanding the potential of historical agroecological systems in adaptation and resilience. The interlinkage of epistemologies

can also be beneficial not only for a single social group, but for local communities, the scientific community and local institutions.

1.4. *Milpa* and indigenous knowledge

One of the most ancient traditional agricultural systems that continues to be of great interest and where indigenous knowledge plays a crucial role, is the shifting cultivation system of *milpa*. The name *milpa* has its origin in the nahuatl term *milpan* (milli = planted plot, pan= over) meaning “what is planted over the plot” (CONABIO, 2016). Traditional *milpa* cultivation consists of the slash and burn of a piece of land that intercrops maize (*Zea mays*) with different other species such as beans (*Phaseolus vulgaris*), squash (*Cucurbita spp.*) and pepper (*Capsicum spp.*) in combination with small quantities of a variety of other seasonal crops using ancient practices and indigenous knowledge (S. Terán & Rasmussen, 1994).

Milpa is considered the most important shifting cultivation system in Mesoamerican tropical areas, though one of the most vulnerable to climate change effects since it is generally not irrigated and thus highly dependent on rainfall for its management (Hernández Xolocotzi et al., 1995; S. Terán & Rasmussen, 1994).

Throughout Mexico and Central America, different types of *milpa* are practiced under varying conditions. Different environmental, cultural and socioeconomic characteristics are associated to it, recognizing the *milpa* as an interconnected and biocultural system (Barrera-Bassols & Toledo, 2005). The different types of *milpa* across areas reflect the type of soil, microclimatic conditions and crop varieties, but also depend on the needs of the farmer, family preferences, beliefs, indigenous knowledge and local practices (Barrera-Bassols & Toledo, 2005; González Jácome & Reyes Montes, 2015; Nigh & Diemont, 2013; Reina, 1967).

Milpa continues to be the basis of the diet of millions of people (Eitzinger et al., 2013) and has a crucial role in providing food security, opportunities for employment and income (CIAT-World Bank, 2018). Studying the *milpa* system through the lens of the inter-epistemic approach and guided by transdisciplinary methods is of great importance in the face of a changing climate, not only to improve our understanding of the changing biocultural meaning of *milpa* but also because *milpa* is vulnerable not only to climatic stressors (Donatti et al., 2019; Eakin, 2000; Ortiz, 2012) but to economic and social stressors (Toledo et al., 2003).

In the Yucatan Peninsula region (Southern Mexico, Belize and Northern Guatemala) the *milpa* system has been practiced throughout different indigenous and mestizo (people of mixed Maya and European ancestry) communities for millenia. *Milpa* continues to be one of the main activities in contemporary Maya farming systems (Nigh & Diemont, 2013), although it has evolved over the last three centuries from what it used to be in terms of composition and management (Harvey et al., 2018; Schmook et al., 2013). This form of adaptation is an example of how social ecological resilience might have developed through time by different generations under different stressors (Toledo et al., 2003).

This is of great relevance for agricultural research considering that despite historical uncertainties, Mayan agricultural practices provided the basis for developing traditional farming systems into more advanced and diverse agricultural systems (Ford and Nigh, 2009; Peters, 2000) that are still practiced in many indigenous communities in the Neotropics.

Despite numerous studies that have been undertaken about the *milpa* system, the indigenous knowledge associated with this system and how indigenous societies adapt and use this knowledge to cope with variable climatic conditions is still not fully understood and thus underused by climate change practitioners when developing coping strategies to assist farmers in developing resilience against extreme climatic events (Alexander et al., 2011). This could be attributed to a lack of understanding by researchers and policymakers of how resilience is built in indigenous and traditional societies and of “the adaptive response of traditional ecological knowledge to new environmental, social or economic factors” (Gómez-Baggethun & Reyes-García, 2013, p. 643). This misunderstanding often comes from the lack of attention given to the epistemology of indigenous knowledge which is based on a reciprocal relationship between humans and nature. When trying to develop strategies this reciprocity could be very beneficial as actions and strategies implemented could be guided by this worldview and farmers will feel more connected to it rather than the current sense of disconnection.

The absence of research around the status of indigenous knowledge within agricultural systems could be causing scientists and policy makers to miss out valuable information on the potential of this knowledge and its capacity to be transformed, transmitted and applied together with scientific knowledge and other knowledge systems, in response to

uncertainties like climate variability (Gómez-Baggethun & Reyes-García, 2013). Understanding changes and adaptation of indigenous knowledge in the context of climate science is therefore crucial to understand how resilience is built in complex and interlinked systems like the *milpa*.

1.5. *Milpa* in the context of climate change and culture.

In the face of a rapidly changing climate, the use of indigenous knowledge and how it has been adapted in the *milpa* system under different environmental and social conditions, needs to be prioritised when studying and analysing the capacity of traditional communities to respond and adapt to known and to new uncertainties and changes.

Different studies have shown that *milpa* has been negatively impacted by climate change mainly because of drought and increased temperatures, frequency of extreme weather events and increase of crop diseases (Mardero et al., 2015; Metcalfe et al., 2020). These changes often impact agricultural soils by altering nutrient cycles, causing soil degradation, affecting microbial communities and reducing agrobiodiversity (Longbottom et al., 2022; Moreno-Espíndola et al., 2018).

Assessment of changes in local conditions (weather and soil) is often done using insight from empirical data (e.g. weather stations; soil health assessment) and has been useful to understand climate-induced changes in land use and management. Given that *milpa* continues to be practiced in many Maya communities as a rain-fed system, studying adaptation from an environmental and scientific perspective is useful to understand which climatic events affect farmers the most and how farmers adapt their land management strategies based on their perception of local conditions and the impact of climatic events. Linking physical and environmental dimensions with human dimensions (e.g. culture and use of knowledge) can improve our understanding of relevant aspects embedded in the adaptation process.

In studying multiple dimensions of climate change in the context of *milpa*, an aspect to be considered is the cultural context of climate change impacts, more specifically the role of culture in climate change perceptions and adaptation (Becken et al., 2013; Whitmarsh, 2011). Perception of climate change is a process constructed by individual, social and cultural factors (Weber, 2010; Whitmarsh & Capstick, 2018) that can be influenced by aspects such as life experiences, exposure to extreme climatic events, beliefs, cultural identity, access and reception of information, amongst others (Weber, 2010).

The variability in these factors is crucial to understand individual decision making related to climate change adaptation given that perceptions are not necessarily constructed in the same way, even if belonging to the same ethnic group or exposed to the same socio-economic and environmental conditions, mostly since perception is considered a subjective phenomenon (Mase et al., 2017). In analysing people's perception and adaptation mechanisms, the cultural context is often given less attention compared to environmental contexts.

Becken et al. (2013, p. 33) highlighted how important it is “to understand the cultural context as a crucial factor in the social construction of climate change”. In biocultural systems like *milpa*, indigenous perceptions and knowledge needs to be studied, not only in terms of how it has evolved and continues to evolve (Gómez-Baggethun & Reyes-García, 2013), but to understand how similar ethnic groups make sense of changes within their own territories and the role of indigenous knowledge (and other knowledge systems) when building resilience and adaptation strategies (Nakashima et al., 2012; Wildcat, 2013). In doing this, there is the potential to enhance the usefulness and validity of indigenous knowledge to bridge research around adaptation and resilience strategies, particularly in areas with limited access to climate records (Becken et al., 2013) without reducing it to merely people's mystical beliefs.

Equally important is to understand how indigenous knowledge can be guided into local and national policies to support local livelihoods and economies and increase their resilience (Gómez-Baggethun & Reyes-García, 2013). This is particularly important as some of the conceptual gaps in relation to how exactly climate change is influencing and reshaping knowledge systems are associated with aspects often dismissed, such as the role of power, politics and institutional frameworks and how these interact and reshape knowledge systems (Hulme, 2010).

To date, few studies have explored the value of indigenous knowledge from a cross-national, multifactorial and transdisciplinary perspective and focusing on epistemological pluralistic approaches. Particularly, information about how exactly the process of indigenous knowledge adaptation occurs in similar contemporary indigenous contexts and which factors can influence knowledge adaptation, is still limited and continues to be, for the most part, unexplored.

1.6. Research Aim and Objectives

1.6.1. Aim

Aim: To document and understand the views, experiences and capacities that Maya Yucatec farmers use to cope with the effects of climate change in *milpa* systems in Mexico and Belize and the role of indigenous knowledge in this coping capacity.

1.6.2. Research Question

The research question sustaining this study was:

What environmental, cultural and socio-economic aspects do indigenous small-scale farmers prioritize when building resilience to climate change and how do they use and adapt indigenous and other knowledge systems to develop this resilience based on these priorities?

1.6.3. Research objectives

The objectives of the research were the following:

1. Document differences in environmental and socio-economic conditions across different *milpa* systems and how these conditions shape farmers' priorities, perceptions, knowledge systems and adaptation strategies.
2. Identify the types of knowledge that Maya Yucatec farmers in Mexico and Belize associate with the *milpa* system in small-scale farms and their role and priority in climate change adaptation.
3. Understand the dynamic process of change in *milpa* management and how this affects the mechanisms by which indigenous communities use and adapt knowledge systems when building resilience to climate change.
4. Identify key informational intersections between indigenous and scientific knowledge in order to describe the potential advantages and challenges of indigenous knowledge in climate change adaptation strategies at a local level.

1.7. Thesis Outline

This thesis is organised into the following chapters

Chapter 2. Literature Review

This chapter begins with an introduction to the epistemological framework around indigenous knowledge, which includes an in-depth review of the notion of indigenous knowledge, explores indigenous knowledge epistemology, and describes the relationship between nature and society followed by a conceptualization of the relevance of indigenous knowledge in agricultural systems.

The concepts of climate change, resilience and adaptation in agricultural systems from a global perspective are reviewed and the multiple factors influencing climate change adaptation and resilience are thoroughly explored.

The relevance of microclimates, power, politics, government/institutional frameworks and indigenous knowledge for climate change science and particularly for resilience and adaptation are explored in depth in relation to agricultural systems.

Subsequently, climate variability and climate perceptions in the context of Latin America and the Caribbean and particularly in the Yucatan Peninsula in relation to traditional farming is explored to set the background for the present study.

The last portion of the chapter offers an in-depth description of the traditional *milpa* and the economic, social and cultural relevance of it. It is followed by a thorough review of the traditional Maya *milpa* and its historical context, to further discuss the interconnection of it with climate change. The chapter finishes by exploring the role of power, politics and institutional frameworks within the Maya *milpa* to conceptualize the importance and relationship of these factors with climate change and knowledge systems. In particular, it addresses the current gaps in the literature and provides foundational insights which strengthen the argument for the importance of this research study.

Chapter 3: Methodology

Chapter 3 provides an overview of the research approach, the research design and data collection and analysis. The chapter begins with a description of the framework for multiple knowledge integration from a transdisciplinary and epistemological pluralistic approach given the inclusion of both indigenous and scientific knowledge systems. This

is followed by an in-depth reflection on working with indigenous peoples and their territories, resulting in a description of the ethics, the researcher's positionality and the implications of working with indigenous knowledge in the context of academic research. The context of the study areas, pilot stage, participant recruitment and datasets for collection are described, followed by a detailed description of the data analysis conducted. The impact of Covid-19 and extreme weather events on data collection and on the research in general are then considered.

Chapter 4, 5 and 6: Results

Results of the research are presented in these three chapters. Both qualitative and quantitative data are integrated, as well as indigenous and scientific knowledge and comparisons made between the two countries. Chapter 4 focuses on providing a reflection of the current status of *milpa* and the multiple factors that have played a role in its dynamic of change. Three main elements are considered: nature, agriculture and knowledge systems. Chapter 5 relates to an integrated approach to soil health within the *milpa* system in which both scientific and indigenous resources are used to understand this functionality in the context of climate change. The chapter also describes the linkage between soil health and elements such as climate variability and use and adaptation of knowledge systems. Chapter 6 presents insights into the past and present changes observed in climate from both a scientific and farmer's perspective and how they align or differ across countries. It examines the impacts of climate change on the *milpa* system and within different knowledge systems and the similarities and differences in adaptation strategies implemented by Maya Yucatec farmers between countries.

Chapter 7: Discussion

This chapter provides a detailed examination of the significance of integrating and comparing both qualitative and quantitative results from Chapters 4, 5 and 6 and offers insights about the contribution of the research to the study of the Maya *milpa* in the face of a changing climate. The discussion brings together the main elements currently associated with *milpa* from a farmer's perspective and links these with how knowledge systems (indigenous and scientific) are used and adapted to cope with the impacts of climate change. Chapter 7 also presents a short reflection on the importance of integrated approaches in researching socio-ecological systems.

Chapter 8: Conclusions

The final chapter presents a summary of the key findings of this study and how they relate to the research question, the research aims and the objectives. Given the nature of the research it also presents a summary of the implications of the findings for traditional agriculture, for climate change, for biophysical conditions, for knowledge and for the future of *milpa*. Highlights of both the academic and societal contributions, limitations and suggestions about future related research are also presented.

CHAPTER 2. LITERATURE REVIEW

2.1 Indigenous Knowledge Epistemological Framework

2.1.1. Indigenous or traditional knowledge: Conceptual highlights.

In studying indigenous knowledge (referred to this study as IK) there are different terms that often are used interchangeably. The three main terms are indigenous knowledge (IK), traditional knowledge (TK or TEK) and local knowledge (LEK or LK), with IK and TK the most frequently used. Although closely related and transmitted through generations, indigenous and traditional knowledge are distinct concepts since they differ in scope, origin, and the contexts in which they are used.

Traditional ecological knowledge (TEK) according to Berkes (1999, p.8) is “a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living things (including humans) with one another and with their environment”.

The concept of TEK became widely used in the 1980s, although the use of this knowledge had existed since ancient times and had been associated with the traditional lifestyle and origins of many prehistoric cultures (Inglis et al., 1993). TEK's importance was first recognized by the International Conservation Union Programme on Traditional knowledge for Conservation due to the impact this knowledge system can have on western science in complementing different scientific research areas (IUCN, 1986). There has been however a debate on the ambiguity and definition of the term due to the many elements involved (K. P. Whyte, 2013)

Nazarea (2006, p. 323) points out that TEK is built through experience “and embodied in everyday practice, it is not logically formulated apart from what makes sense from living day to day in one's environment; nor is it inscribed as a set of processes or rules”. McGregor (2004, p. 396) argues that TEK include many aspects related to spirituality and to relationships with the land. In his words “TEK is a ‘way of life ‘a relationship that requires doing”, it is action-oriented (a verb) rather than being just a knowledge (a noun).

Although many scholars have proposed different definitions, the one proposed by Berkes (1999) has been widely recognised and used across many disciplines, including agriculture because it is a “situated knowledge”.

According to Dudgeon & Berkes (2003) much of the literature around knowledge systems has been developed in relation to differences and similarities between TEK and Western science, but limited literature is available about the differences between the concepts of TEK and IK. Recent literature has argued that distinctions between the conceptualization and use of IK and TEK have remained ambiguous, inconsistent and overlapped (Duarte et al., 2020).

Within the literature available, the main distinction between IK from TEK is that the first refers to the unique local knowledge of indigenous people (Warren et al., 1995), while TEK is a broader concept because it can be part of indigenous knowledge, but it is not limited to an indigenous group. TEK can include knowledge of non-Indigenous cultures and local groups and passed orally and written across generations, but also considers an “explicitly ecological emphasis” (Dudgeon & Berkes, 2003, p. 76). Mistry (2009, p. 371) argues that although TEK and IK share some commonalities “defining IK is a highly contested issue” and there are specific characteristics that should be considered when using this concept.

Indigenous knowledge (IK), as defined by the United Nations Educational, Scientific and Cultural Organization (UNESCO), is expertise developed by indigenous societies about their natural surroundings. However, there are important aspects to consider when trying to define IK which have been discussed by both scholars and members of different indigenous groups.

Indigenous communities have stated that IK possesses specific characteristics that make it unique to the places that indigenous people inhabit and that has helped them to connect with nature for many years and is embedded in their culture, their identity and their daily life (Smith, 2021). Lutomia & Bello-Bravo (2017) supported this argument by stating that IK is context-specific knowledge often tied to specific territories or ways of life.

Rarai et al. (2022, p. 2243) described IK as “a place-specific nested knowledge system of information-practises-values” and argued that amongst many scholars it is considered as “highly dynamic and derived from the accumulation of collective past experiences of a particular group of people about their local environments”. Dhungana et al. (2023b, p. 335) defined IK as “perceptions, information, and behaviours that guide indigenous people to utilize and manage their natural resources”. But IK is also holistic and adaptive, characteristics that are often overlooked.

Dudgeon & Berkes (2003, p. 75) have also argued that the term “knowledge” within the concept of IK is specially focused on highlighting “the contrast between local ways of knowing versus dominant understandings derived from modern science”.

Mistry (2009) summarized this diversity of characteristics from IK as follows: 1) Local or context specific to an indigenous group; 2) orally transmitted or through imitation and demonstration; 3) adaptive not static and constantly changing; 4) holistic, socially differentiated and preserved in the memory of specific individuals.

Within different research studies, a conceptual debate continues to be discussed, and many authors continue to use TEK and IK interchangeably, however for the purpose of this research given that it focuses on a specific indigenous group and on a locally informed perspective to link it to modern science perspectives (Sillitoe, 1998), the term IK has been chosen as the most appropriate one.

2.1.2 The epistemology of indigenous knowledge

IK epistemology refers to the ways in which Indigenous peoples acquire, validate, and transmit knowledge within their communities, emphasizing a worldview that is often distinct from Western modes of knowledge. This epistemology is deeply rooted in lived experience, oral traditions, relationships with the land and nature and spiritual practices, and is passed down through generations (Battiste, 2002; Wilson, 2008).

Central to this understanding is the interconnectedness of humans, nature, and the cosmos. Knowledge is viewed as dynamic, relational, and experiential, rather than objective or static, and is often context-specific, reflecting the unique history, culture, and environment of each indigenous group (G. Cajete & Little Bear, 2000).

In contrast to Western epistemologies that prioritize individualism, objectivity, and scientific empiricism, IK is collective, holistic, and embodied. It recognizes the agency of non-human beings, the importance of place and memory, and the ethical responsibilities tied to knowledge sharing and stewardship (Lujan & Glover, 2020; Smith, 1999). Indigenous ways of knowing also prioritize the lived experience and wisdom learned through participation, observation, and reciprocal relationships with the natural world (Deloria, 2003; Wilson, 2008).

Historically, IK systems have often been marginalized or dismissed in favour of Western scientific frameworks, especially in the context of colonization (Smith, 2021). However,

usefulness and value of these knowledge systems in contemporary contexts, especially in environmental conservation, climate change mitigation, and sustainable practices has been increasing (Garibaldi & Turner, 2004).

Indigenous epistemologies are now recognized not only as sources of indigenous knowledge but as essential for addressing global challenges by offering alternative ways of knowing and being in the world and helping to understand the unique relationships that indigenous peoples develop with nature within their territories (K. P. Whyte et al., 2016).

2.1.3. The human-nature relationship in indigenous knowledge systems

Human-nature relationships refer to the complex interactions between human societies and their natural surroundings. These relationships have been present across time and have continually evolved for human societies to survive (Milfont & Schultz, 2016). Human-nature relationships have been subject to study in many disciplines across the world but have often been less considered in relation to complex challenges such as climate change and largely reduced to social or cultural elements.

According to Eversberg et al. (2022), there are different types of relationships with nature, based on the emotional, cognitive, and practical ways in which individuals and communities engage with it. These relationships are shaped by cultural, social, and personal factors and there are three main approaches in research on how individuals or social groups relate to nature.

The first approach relies on empirical observations, often from an individualistic perspective, which studies nature-related values, attitudes, perceptions and their links with different social characteristics and behaviours and how relationships with nature change across time.

A second approach is based on studying the different types or models of human-nature relationship often through qualitative data that allows “similar nature-related worldviews and lifestyles”.

A third approach, which is rooted in ethnographic work, is focused on conceptions and interactions with cosmologies and relational networks in non-western social contexts and the “different experience-based ways of dealing with these cosmologies by different groups”. These approaches often have “little to say about the relevance of differences

and changes to processes at a societal level as we understand them” or “how they relate to each other and to a larger societal whole” Eversberg et al. (2022, p. 394). As a result, the authors also described four elementary forms of relationship with nature that societies may have and that are relevant to overcome socio-ecological crisis: natural capital; nature as partner (reciprocal relationship with nature); natural heritage and nature as environment.

Understanding the different existing relationships with nature is crucial for addressing global challenges, especially because the level of interaction with nature can affect how societies perceive and act to solve environmental challenges (Milfont & Schultz, 2016).

According to Milfont & Schultz (2016, p. 194) “the ways individuals relate to nature are culturally patterned”. This is because cultural factors surrounding societies can shape beliefs about nature and how it works and consequently how individuals interact with nature.

In many cultures around the globe humans are still deeply inter-connected with nature (UNDP, 2023) through a unique relationship of mutual need, reciprocity and caretaking (Dhungana et al., 2023a). In indigenous societies, the main principle of human-nature relationships is that nature is seen as a partner (Eversberg et al., 2022), in which societies make sure that the balance within the land they inhabit is maintained so that they can continue to have access to ecosystem services like food, water, fertile food, etc. (UNDP, 2020) in what is called an ethos of care. Ethos of care and a reciprocal relation with nature is the epistemology of indigenous knowledge (Bang et al., 2018).

Leonard et al. (2013) argued that indigenous knowledge is crucial for understanding how resources are used and how environmental risk is perceived locally, hence fundamental aspects of culture need to be considered when understanding the relationship of indigenous societies with nature (Milfont & Schultz, 2016).

The way humans relates to nature has allowed local and indigenous societies to generate a specific “living knowledge” (Dhungana et al., 2023a, p. 351) which is the result of long-term observations and relationships with nature that honours the interconnectedness of life while recognising the sacredness of nature and identifies humans as integral part of it (UNDP, 2020).

Scholars have become interested in understanding the relationship between nature and human in traditional societies, so there has been a need to define the concept of knowledge systems properly and particularly that of indigenous knowledge.

2.1.4. The intersection of Indigenous Knowledge, Agricultural Systems and Climate change.

The study of IK has been explored by many disciplines, but there are some specific fields which are pioneers in these studies, such as anthropology, agriculture and ethnobotany. Most of these studies, however, have been developed on the use of TEK rather than IK, given the conceptual gaps that continue to be debated.

One of the oldest studies, considered a model of the role of traditional ecological knowledge and from which present studies on indigenous knowledge have their origin was done by Freeman (1955). He described a traditionally based shifting cultivation of rice with different Malaysian crops and the traditional knowledge associated with this cultivation technique. Four main aspects were studied which included agricultural techniques, economic aspects of agriculture, land tenure and land usage and challenges of the cultivation strategies. Descriptions of the social and cultural aspects were also discussed. The results of this study set the basis for many ethnographic studies of traditional agricultural systems and set a precedent for modern studies of the importance of traditional and indigenous knowledge in agriculture.

Numerous studies aiming to understand how small-scale farmers cope with climate change effects through the exploration of indigenous knowledge and climate variability have been developed in different regions across the globe (Beckford & Barker, 2007; Boillat & Berkes, 2013; Gómez-Baggethun et al., 2012; Mertz et al., 2009). Amongst these studies the authors have discussed and concluded the importance of IK as a crucial component of adaptive capacity to increase resilience, mostly because it co-evolves with social and ecological systems (Colding et al., 2003) and is created around specific relationships with nature (Berkes, 1999).

For many years an ongoing debate around the importance of IK has highlighted the lack of recognition of this knowledge within regional and local climate change institutional frameworks (Ford et al., 2016; Maldonado et al., 2016). However, in recent years scientists and policy makers have highlighted the importance of merging IK with scientific knowledge to cope with climate change challenges and develop adaptation

strategies (IPCC, 2019). The Intergovernmental Panel on Climate change (IPCC) has recognised that indigenous knowledge that is part of agricultural practices, can help to address the challenges of climate change from both an environmental and social perspective and that all stakeholders involved in the agricultural sector need to work jointly with indigenous people and local communities to design better local adaptation strategies (IPCC, 2019)

Despite IK (referred sometimes as TEK) and its potential to address key environmental challenges has been studied since 1980, there are many elements of IK that remain to be understood (Alexander et al., 2011). For example, although several studies have been conducted around the transmission and acquisition of IK (Constant & Tshisikhawe, 2018; Lozada et al., 2006; Zarger, 2002), one of the elements that has been overlooked is related to its own resilience as a knowledge system (Gómez-Baggethun & Reyes-García, 2013). According to Ford et al. (2016, p. 350) IK has “commonly been treated as a static form of knowledge... overlooking the highly dynamic and evolving nature of TK”. [sic]

This argument coincides with Gómez-Baggethun and Reyes-García (2013) study on the resilience of traditional knowledge systems in response to environmental, socio-economic and cultural changes. Their analysis of traditional knowledge in different places around the world suggested that despite what other authors have hypothesised regarding an increased loss in transmission, this knowledge system is persisting, but adapting and going through a process of hybridisation. The authors argued that this is occurring through the “accommodation of new forms of knowledge” defining knowledge resilience as “the capacity of society to retain the ability to generate, transform, transmit, and apply TEK”. [sic] (Gómez-Baggethun et al., 2013, p. 4).

Therefore, studying how climate change resilience is built in agricultural systems should also consider the potential of this capacity to be developed in other contexts such as the one related to the knowledge systems. This is particularly important considering how varied indigenous knowledge is, its relationship with agriculture and how it continues to be used by different cultural groups (Kom et al., 2024). Understanding the process of use, change and adaptation of knowledge systems could not only help to develop better adaptation strategies but enhance farmers’ capacity to cope with challenge.

2.2 Climate change

2.2.1. Defining climate change

According to the IPCC, climate change can be defined as a change in the state of the average weather (climate) that persists for an extended period (long term changes) and which can occur due to natural internal processes or external forces (IPCC, 2018). Human activities are probably the biggest contributors to the observed changes in climate (heatwaves, heavy precipitation, droughts and tropical cyclones), and indeed, weather (atmospheric conditions in a specific place at a specific time) and climate extremes have been recorded in every region of the globe (IPCC, 2023). The Climate Change 2023 Synthesis Report of the IPCC detailed that cold extremes have become less frequent and less severe, while hot extremes (including heatwaves) have become more frequent and intense across most land regions (IPCC, 2023).

The State of the Global Climate Report supported this by reporting that 2023 was the warmest year at 1.45 ± 0.12 °C above the 1850-1900 average surpassing the two previous joint warmest years 2016 (1.29 ± 0.12 °C) and 2020 (1.27 ± 0.13 °C). In addition to this, the report also stated that the past nine years (2015-2023) have been the warmest ever recorded (World Meteorological Organisation, 2024). The impacts of this increased temperature have been accompanied by intensity and frequency of extreme weather events like floods, hurricanes and droughts whose effects have been widely felt globally. In terms of precipitation, heavy precipitation events have increased, as well as ecological and agricultural droughts. Similarly, major tropical cyclone occurrence across the globe has also increased in the past four decades (IPCC, 2023).

Currently between 3.3 billion and 3.6 billion people live in countries that are highly vulnerable to climate impacts, concentrated in the Arctic, Central and South America, Small Island Developing states, South Asia and much of sub-Saharan Africa. In terms of economic impacts climate change has caused economic damages to climate-exposed sectors including forestry, fishery, energy, tourism and agriculture (IPCC, 2023).

2.2.2. Climate Change in the context of agricultural systems in Latin America and the Caribbean.

Land ecosystems under agriculture and forestry are considered amongst the most vulnerable to environmental change, not only for the impact that extreme events can

cause to ecosystem functionality, but for how this can directly affect many livelihoods around the world that depend on land for food supply and income (IPCC, 2023).

The consequences of climate change have been already felt in agricultural systems from the Global South (Apraku et al., 2021), like those in Latin America and the Caribbean, due to increasing temperatures and lower rainfall, impacting agricultural productivity in a considerable number of crops like maize (IPCC, 2023). These concurrent and repeated climate hazards are increasing impacts and risk to ecosystems, infrastructure, livelihoods, food and health (IPCC, 2023).

Efforts guided and assessed by the IPCC have been put in place to help governments build a climate change framework that could help cope with the impacts of climate change on agricultural systems. However, some gaps have been found and the need for integration not only of biophysical elements, but cultural and socioeconomic factors has been highlighted given their influence in peoples' livelihoods, food security and health (IPCC, 2023).

In Latin America and the Caribbean the analysis of socioeconomic and cultural aspects is of high relevance not only because many people are living in poverty and because agriculture and tourism are some of their main sources of income, but because of where many countries in this region stand in terms of the global economy (e.g. upper middle income for both Mexico and Belize; World Bank, 2020).

In Mexico and in Belize, as in many other developing countries across the region, climate change is considered a coupled issue because it affects not only the environment but also social and global and regional economic conditions (Johns et al., 2013) that can fragment local livelihoods (Verner, 2011). This has been described as a “double-exposure” (O’Brien & Leichenko, 2000) and represents a threat to the agricultural sector as a whole but also to small-scale farmers who can be impacted by the reduction of crop prices, inequitable competition with cheaper products been imported and lack of access to credits, subsidies, and inputs given to farmers to assist with crop managements such as seeds, fertilizers and irrigation (Mittelman, 1994).

In that sense, studying how climate change effects are impacting crop productivity, the markets associated with them and the influence of institutional programmes is highly relevant, but still needs in depth analysis. Some studies have been developed around climatic variability, crop production and the influence of national agricultural policies to

understand differentiated vulnerability (Eakin, 2000; Eakin et al., 2014; Tucker et al., 2010).

Research has been developed mostly around crops that are considered staple foods, such as maize, and using ethnographic data collection as a method to assess the different resources that farmers use to cope with uncertainties, with a specific focus on how institutional processes and changes in the economy influence impacts on livelihoods (Eakin, 2005; Mardero et al., 2018). These studies are like those conducted in farming systems in India, Southeast Asia and Sub-Saharan Africa, where reviews of policies and programme responses have been conducted to determine the characteristics that allow communities to build resilience and respond to climate change and food insecurity (Brooks & Loevinsohn, 2011).

These studies are of relevance as they have shown how communities continuously adapt and the drivers influencing such adaptation. There is a need, however, for developing further analysis around the impact of climate change on farming systems and food security, but interlinked with other non-environmental aspects that might be contributing to farmers' resilience such as the influence of social networks, institutional frameworks or the use of indigenous knowledge systems specifically within countries with ethnic diversity such as Mexico and Belize. Up to now most of the climate change studies conducted in these countries have left out key aspects that are also relevant to resilience and adaptation.

2.3 Climate change resilience and adaptation.

2.3.1. Understanding the concept of resilience

Across the globe, climate change action has sparked debates about resilience and adaptation, topics that have been widely studied (Ackerl et al., 2023; Eakin and Luers, 2006; Adger et al., 2005; Smit et al., 2000).

The term resilience was first introduced in the early 1970s to describe the capacity of a system to absorb disturbances, or withstand stress, while stable and functional (Holling, 1973). Although this term was first used to refer to the ecological resilience of ecosystems, the term has evolved over the past two decades and its use widened, being adapted and applied to different systems across sciences like agricultural and food systems or other socio-ecological systems using different methods to define, understand and study resilience (Martin-Breen & Anderies, 2011).

Within the social ecological systems approach, the term resilience refers to the capacity of systems to adapt or transform to unexpected changes or disturbances so that humanity can be maintained (Biggs et al., 2015). Under this approach resilience is constructed around societies, cultures or communities and the physical elements of nature on which they depend (Folke et al., 2016).

However, in the case of agricultural and food systems, which are characterised by interconnecting factors including ecological, social and economic aspects the concept of resilience has attracted significant research attention due to its impacts on people's livelihoods (Altieri et al., 2015; Eakin et al., 2014). In this case the definition of resilience has mostly been used to understand how these systems adapt to the effects of climate. Resilience has then been defined by the IPCC (2018 p. 557) as “the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation”.

Currently there are still some challenges being faced when trying to design measurement tools (Phuong et al., 2023) and this has also opened the door for more in-depth research on aspects often overlooked from the resilience literature such as ethnicity and gender (Tran et al., 2022).

When researching how resilience is built, particularly in the context of agricultural and food systems, one of the most argued debates comes from understanding the complexity of these systems from two dimensions: how to recover from disturbances and how to adapt to changes (Gitz and Meybeck, 2012). The process of building resilience is embedded with the notion of vulnerability, adaptation, transformation, renewal and innovation (Adger et. al., 2005; Eakin and Luers, 2006; Folke, et al., 2003, 2006; IPCC, 2022). Within these elements, adaptation constitutes an important characteristic of resilience.

2.3.2. Linking resilience and adaptation

Adaption has been defined as “adjustment in the face of change” based on the knowledge of past, current or projected conditions and is used to describe behaviours that are adopted by people, communities, or sectors (Martin-Breen and Anderies, 2011). In the context of

climate change, this concept has mostly been used to understand how people respond to the observed or expected impacts of climate change.

Overall, the notion of adaptation refers to the adjustment that systems experience within their structures, practices or processes in response to observed or expected changes of climate (Adger et al., 2005; Smit et al., 2000). The IPCC defines climate adaptation as “the process of adjustment to actual or expected climate and its effects in order to either lessen or avoid harm or exploit beneficial opportunities” (IPCC, 2018, p. 542).

Adger et al. (2011, pp.757-758) proposed that a resilient system in response to climate variability is characterised by its ability to “learn, innovate and change” and that both resilience and adaptation are interlinked to multiple sources within systems which need to be deeply understood to provide support to policy strategies. This coincides with Biggs et al. (2015) who argue that understanding how resilience is built requires a deep comprehension of how different key factors affect systems. Folke et al. (2016) contribute to the argument by recognizing that there is a need for using different approaches that can continue to help understanding the relationship between human well-being and nature and the capacity of humans to shape and reshape this relationship.

In the face of a changing climate, therefore, the concept of resilience in agricultural systems needs to be examined from different perspectives including biophysical, economic, social and institutional, whereas adaptation should be studied from a socioeconomic (livelihoods) and environmental (ecosystem) level at different scales to understand how resilience is built (FAO, 2012).

Findings from Sterling et al. (2017) around resilience using multiple approaches explored which indicators and criteria can be identified to capture the social, cultural and environmental context in which social-ecological systems are managed and, therefore, how resilience is developed and implemented. Their analysis demonstrated that the development and use of specific indicators by local people, in their local context, can facilitate the process of adoption and acceptance of response strategies implemented by institutions. These results align with arguments proposed by other authors that to be able to understand how complex systems are capable of coping with change and uncertainty requires resilience building thinking, framed around governance, institutions and social networks through dynamic learning processes (Altieri et al., 2015; Carpenter & Gunderson, 2001; Folke et al., 2002).

When studying resilience and adaptation to climate change in agricultural systems it is important to consider the definition of vulnerability. In the climate change scenario, the concept of vulnerability has been discussed by various authors (e.g. Adger, 2006; Eakin and Leurs, 2006;) and has been defined by the IPCC as “the propensity or predisposition to be adversely affected” (IPCC, 2018, p.560). It is considered a “dynamic concept, varying across temporal and spatial scales and depends on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors” (Gitz and Meybeck, 2012, p.20). It is also defined as a “function of exposure, sensitivity and adaptive capacity” to stresses (Adger, 2006, p. 274). In agricultural systems the concept of vulnerability has been used and examined to refer to climate hazards and livelihoods (e.g. social vulnerability) and the capacity of building resilience (Eakin, 2005), therefore when researching resilience and adaptation it is important to be aware of this concept. However, for the purpose of this study the approach taken to understanding people’s coping mechanisms will be through the lenses of resilience and adaptation.

Resilience and adaptation to climate change have been studied in different parts of the Global south across different traditional farming systems, mostly on rainfed systems and based on physical science rather than through the approach of local people’s perceptions (Chaudhary and Bawa, 2011; Eakin et al., 2014; Ingty et al., 2017; Li et al., 2013; Viguera et al., 2019). Understanding the concept of resilience and adaptation through understanding people’s experiences and perceptions is important to structure the right approach applicable to specific issues in the agricultural systems; in particular, to find optimal strategies that could help to maintain local people’s livelihoods and well-being in the face of global change.

2.4 Factors influencing climate change adaptation and resilience in agricultural systems in Latin America.

2.4.1. The role of microenvironments.

Microenvironments are known for offering diverse and multifaceted opportunities to support human resilience amidst climate change, yet many of the local climate adaptation strategies and policy makers continue to dismiss the relevance of this (Altieri et al., 2015; Mijatovic et al., 2013).

Microenvironments such as crop diversity, climate conditions and soil diversity are essential to the climate change resilience of agricultural landscapes due to the impact

they can have on crop productivity (Mijatovic, et al., 2013). Soils in particular, play an important role when developing solutions and strategies to climate change as they are considered one of the biggest reservoirs of soil organic carbon (SOC). SOC provides essential functions such as water retention and nutrient cycling, which are essential for agriculture. Studying this microenvironment at local levels in areas with high climate variability is relevant as climate is the main driver of SOC decomposition and research has shown that variable weather patterns (e.g. increased temperature or rainfall variability) can accelerate SOC loss (Longbottom et al., 2022). Intensification of certain agricultural practices (e.g. chemical pesticides) and a lack of assessment of soil health could lead to disturbance of soils, leading to soil degradation, soil erosion and SOC losses. Despite this, in many countries from the Global South that are dependent on rain-fed traditional agriculture and with a high diversity of soils, often limited attention is given to soil.

In Latin America, despite being known for having diverse ecosystems and climatic conditions, literature on how microenvironments can support climate change adaptation and resilience is still limited (Fenzi et al., 2022; McQueen & Treonis, 2020; Pérez & Becerril, 2023; Quintero Carolina et al., 2023; Vignola et al., 2022). Specifically, for Mexico, despite being known for its distinctive soil environments (Bautista et al., 2011) used for traditional agriculture few case studies have focused on analysing microenvironments when studying maize in the context of climate change and resilience (Bellon et al., 2011; Fenzi et al., 2021). In Belize, research around microenvironments and climate change has been focused mostly on agroforestry but mostly focused on cacao (McQueen & Treonis, 2020).

Latin America and the Caribbean also plays a key role for food security since it is considered a leading supplier to the world food market due to quality land and prevailing climate for agricultural diversity (FAO, 2014); but also since more than 50% of the food production in this region comes from smallholder farmers (World Bank, 2020). Despite this relevance, the role of microenvironments in climate change adaptation and resilience in the context of agriculture continues to be overlooked. In Mexico and Belize where small-scale agriculture is the main provider of rural livelihoods as 57% of the farms in Mexico are small-scale (Ibarrola-Rivas et al., 2023) and in Belize 57% of the landholders are small-scale farmers (CIAT; World Bank, 2018), little is known about the importance of microenvironments in the resilience of these agricultural systems.

Research focused on seed security systems, local farming systems and climate change impacts in other parts of the world (mainly in Africa) have shown that there is a lack of understanding of the microenvironments and of farmer's knowledge around diverse agricultural environments when developing support strategies. Understanding the role of microenvironments and farmer management strategies in the context of climate change has proven to be important since these can provide localized solutions to climate stresses (Fenzi et al., 2022; Kansiime & Mastenbroek, 2016). For example, assessing microclimates within farms can help to promote better ecosystem-based practices and enhance farms' natural assets (soil, water, biodiversity; Vignola et al., 2022) to help crops survive periods of drought or intense rainfall, but farms are often viewed as homogenous environments and landscapes.

In-depth characterisation of microenvironments could allow for diversification of crops in response to unpredictable weather patterns, reducing risks from climate variability and enhancing soil health through sustainable practices to secure food security (Klein et al., 2003; Longbottom et al., 2022), but could also result in better support programmes and implementation of cost-effective climate change adaptation strategies, policies and institutional frameworks which often are put in place without a proper assessment of the local environments (Sperling, 2008).

2.4.2. The role of policies, institutional frameworks and politics.

Thornton et al. (2011, p. 118) point out that “rural communities and households continue to demonstrate tremendous adaptive capacity in the face of economic and social change, but this capacity needs appropriate social, institutional and political support”. Agricultural policies in several countries in Latin America and the Caribbean are progressing and have been guided to switch to a markets-approach (ECLAC, 2017); however, some countries are shifting towards integrated risk management policies in the form of yield and harvest insurance programmes, or multi-year support programmes through subsidies. This type of approach is mostly occurring in Argentina, Brazil, and Mexico (ECLAC, 2017). Regardless of the approach, changes cannot be done solely by farmers and if shifting strategies, this process need to be well supported (Thornton et al., 2014).

In small Caribbean countries like Belize, agricultural policies have used market-led strategies to increase diversification, promote self-sufficiency in products and climate

smart agricultural practices, but also promoting non-traditional export crops (e.g. citrus and bananas; CIAT-World Bank, 2018). The Food and Agriculture Organisation (FAO) Strategic Work for inclusive and efficient food systems (FAO, 2014), recognized that there is still a big gap in terms of understanding which are the factors that can allow farmers to create and adopt management cultivation strategies around domestic markets and food systems so that they are beneficial for them which could be rooted in a lack of institutional support and guidance.

Examining the differences between institutional support in a vulnerable to climate change region like the Yucatan Peninsula could provide insights into what could be the long-term consequences if unsuitable efforts in agricultural production and food security are implemented (McGuire and Sperling, 2013; Sperling, 2008) and how policies can be better adapted.

The IPCC has remarked that each farming context has different needs and therefore needs to develop different supporting policies and strategies at different levels (IPCC, 2019), but it is necessary to examine how resilient the support in areas that share climate vulnerability is, to fill the gaps in climate adaptation policies. In this sense, the IPCC also highlights that challenges in agricultural systems and climate change adaptation strategies can be limited if they are not site-specific or not linked between the local biophysical changes and the social and institutional conditions (IPCC, 2019). There is thus a need to study the ability to build resilience in local climate change institutional frameworks and agricultural policies in the face of a rapid changing climate.

In Mexico and Belize climate change and agricultural policies appear to be different in terms of the approach towards supporting farmers, despite being in the same geographical area and despite being impacted by similar climatic variability and exposure to climatic extreme events. In general, in Mexico, public policies developed have looked at promoting resilient agroecosystems through the integration of multiple resilience resources across scales and integrate complex agricultural system dynamics (Mikery-Gutiérrez et al., 2020).

The policy framework in Mexico in relation to climate change has its origins in 2004 with the appointment of a Mexican Committee for Projects to Reduce Emissions and Capture Greenhouse Gases (COMEGEI) as the authority in charge of representing Mexico within the United Nations Framework Convention on Climate Change

(UNFCCC) and the Kyoto Protocol. Later in 2009, the Special Climate Change Programme 2009-2012 was published and the General Law in Climate Change (LGCC) was also created. In the last decade Mexico has had relevant climate change programmes and institutional frameworks aimed at strengthening resilience and adaptation of productive sectors (e.g. agriculture; Mikery-Gutiérrez et al., 2020). The first one is the 2014-2018 Special Climate change Program (IPECC) which in 2022 was shifted to the Special Climate change Program for Agriculture (PLECCA) to focus on achieving productive, fair, diverse, inclusive, sustainable agri-food systems, low in greenhouse gas emissions and resilient to the effects of climate change (Gobierno de Mexico, 2022).

One of the national policies that has focused on risk management and climate prevention and considers the agricultural sector is the 2013-2018 Mexico's National Development Plan. Many important agricultural incentive programmes were strengthened as this policy was focused on productivity, profitability and competitiveness and support for acquisition of insurance for agricultural production but with high focus on large scale agriculture (DOF, 2013). This policy however was refocused with the change of government and political party in charge in 2019, to the 2019-2024 Mexico's National Development Plan to focus on policies with social impact. Agricultural support programmes were shifted not only to support and prioritize small scale agricultural systems, but to make sure farmers' socioeconomic conditions were also considered. Within this framework one of the most popular current agricultural support programmes emerged: Sembrando Vida-Sowing Life (DOF, 2019), which has recently been adopted by the Government of Belize to be replicated in the country.

At a more local level in Yucatan, Mexico the Action Program on Climate Change in the State of Yucatan (Programa Especial de Accion ante el Cambio Climatico en el Estado de Yucatan) was decreed in 2014 to align with the climate change national and state plans in place (DOEY, 2014), however agriculture is not included as a sector to focus on. Within both state and national climate change frameworks the focus is given on environmental contexts and more recently to socio-economic contexts, but the cultural dimension of climate change continues to be overlooked.

Belize has developed several policy frameworks over the last ten years to respond to climate change issues. These include: (1) Horizon 2010-2030 (a plan in the long term); (2) National Energy Policy Framework; (3) Sustainable Energy Action Plan 2014-2033;

(4) National Climate Resilience Investment Plan 2013; (5) Growth and Sustainable Development Strategy 2016-2019 (medium-term plan) and (6) the National Climate Change Policy, Strategy and Action Plan 2015-2020. Out of these six frameworks, only the National Climate Change Policy, Strategy and Action Plan 2015-2020 appeared to consider the agricultural sector more in-depth.

Belize has also developed an Integrated Vulnerability and Adaptation Assessment focusing on relevant impacts of climate change on six priority development sectors: coastal development, agriculture, water, tourism, fisheries and health highlighting Belize's extreme vulnerability. The national framework that has been in charge of working directly with farmers is the Belizean government's Agriculture Extension Service, which has played a key role in working with small-scale holders including those practicing *milpa* (Drexler, 2022).

Belize's Updated National Contribution 2021 report showcased that several of the climate adaptation strategies by sector have a strong baseline within the tourism, land use, infrastructure and human settlement sectors given their vulnerability to climate change. These strategies consider actions from an environmental dimension of climate change (including some microenvironment management such as soil and water), but there is also a key social and cultural component, involving working approaches with local and indigenous communities (UNFCCC, 2021). Other strategies for Belize have also been discussed at the Caribbean Agricultural Policy Forum which have addressed climate change impacts on small producers such as price volatility (Egas & De Salvo, 2018).

Evidence suggests that there is a need of further analysis on the implications of a differentiated capacity to build resilience at the ecological, institutional, livelihood and cultural level.

2.4.3 The role of power and historical dominant discourses

One of the main challenges emerging from the study of climate change impacts and adaptation mechanisms in countries from the Global South is that quantifying these impacts and adaptation mechanisms often is dominated by discourses and methods that use a limited range of scientific parameters and, as a result, limited attention is given to assessments based on indigenous knowledge. Despite the importance of this knowledge and the continued call of the IPCC and other policy frameworks (See 2.3.2) to include indigenous knowledge in climate change discussion, indigenous knowledge continues to

be overlooked in many climate change discourses and methodologies. The top-down approach currently provided by local authorities is an important element to be analysed when studying climate change in agricultural systems and should be considered by local governments and policymakers to provide wider recognition of knowledge systems such as IK when developing local adaptation strategies (Wildcat, 2013).

Institutional support is essential, otherwise there is a risk of losing or marginalising IK. Swiderska & Mutta (2011) found that the lack of support from local authorities and policymakers has been considered one of the main drivers for loss of transmission and degradation of IK, and this poses a challenge considering the lack of studies around the historical and political realities of IK (Simpson, 2004).

Fisher (2020) points out that studying the historical dynamics of change in IKs possessed by small scale indigenous farmers and their relationship with external factors, either political or social, could be the key for securing traditional agricultural systems. Using records of historical maize tribute collection to trace changes and agroecological data, the author analysed the possible causes of the dismissal of indigenous knowledge in local agricultural systems in Mexico between 1400-1600, before and after the contact between Spanish colonisers and Yucatec indigenous groups and provided an insight into why, to date, IK continues to be diminished and not fully recognised by political authorities. The author also states that the main reasons rely perhaps on the governance from top-down and bottom-up support that IK holders might have had before colonialism within their local governance systems, and which could potentially allow holders to fully implement their knowledge by being able to mobilise their farming systems and transmit IK to future practitioners. However, with the establishment of colonial authorities, indigenous farmers and their systems were restricted to certain areas, as a way of controlling indigenous population and the local institutions supporting IK were dismantled as they were considered a threat to authority. Fisher (2020) also highlights that the effects of this post-colonial lack of support are still seen in modern Maya Yucatecan food systems and should be carefully analysed.

2.4.4 The role of Indigenous Knowledge and Culture

Johns et al. (2013) suggested that knowledge possessed by indigenous farmers is a valuable tool that needs wider recognition to identify opportunities for diversifying and improving food systems. The authors remark that this should be done through policies

that consider local agriculture and institutions, local governance, local livelihoods and that are economically viable so that farmers have access to reliable markets and other equitable development opportunities.

In doing this there should be consideration of people's connections to cultural, social, institutional and ecological systems so that they are able to cope with different uncertainties resulting from change. Anderson (2005) is consistent with this argument by emphasising the importance of the local knowledge associated with food systems as a contemporary tool to understand many aspects of past and present food systems; but notes that this type of knowledge is often undervalued and hasn't been given enough recognition, despite the fact that it could help to learn more about how ancient civilizations like the Maya survived severe food insecurity crises in the past and continue to do so. This lack of recognition however has slowly started to change in the face of a rapidly changing world, since researchers and policy makers have acknowledged that understanding how traditional communities cope with changes in their local agricultural systems could improve the world's food systems and nutrition (IPCC, 2019).

The relationship between IK and climate change policies to improve food systems is important to consider because IK in traditional agricultural systems is deeply connected not only with climatic variability, but also to the ecological variability in local environments (Fisher, 2020). A contemporary study on crop and soil variability by Graefe (2003) in traditional and modern *milpa* systems in Yucatan Mexico, found that even though traditional farming systems had evolved from their ancestors and adopted some form of modernisation (use of fertilizers, herbicides and improved/hybrid seeds), traditional practices have continued to be used almost the same way and the traditional knowledge associated with maize varieties, crop species and type of soils is still present and continues to be a key element in different types of *milpa* management .

Therefore, in regions that are vulnerable to climate change and are culturally diverse, like the Yucatan Peninsula (Maya indigenous represent 65.40% of the population in Yucatan State, 12% in Belize and 24.6% in Northern Guatemala; INE, 2011; INEGI, 2015, SIB, 2020), it is important to assess and rethink the design of policies from a biocultural perspective so that they can cope with uncertainties considering among other key elements, the traditional knowledge that is connected to local microhabitat

management (Altieri et al., 2015; Faust & Bilsborrow, 2000). Not doing this, could result in maladaptation strategies.

Indigenous and local societies in several parts of the world, and in different agricultural systems who have faced climate change effects first-hand, have recognised the impact this has caused on their food security (IPCC, 2019). Therefore, there is a need to assess adaption strategies at a local level considering multiple factors and the social, economic, cultural and political barriers to avoid climate change adaptation strategies having a negative effect (IPCC, 2019).

The review of the elements of IK from different perspectives has shown that IK cannot be isolated from the complexities of environmental, social, political, and historical changes, therefore it is important to consider these elements when studying IK in agricultural systems to maximise its usefulness in building resilience and developing adaptation strategies.

2.5 Climate Variability and Climate Perception in agricultural systems in Latin America

Although the effects of climate change have been seen across different agricultural regions of the globe (Karki et al., 2020), Latin America and the Caribbean has been strongly impacted by these effects especially in traditional rainfed agricultural systems (Altea, 2020; Funatsu et al., 2019; Fierros-González & López-Feldman, 2021; Keleman Saxena et al., 2016). In Mesoamerica, these effects have been of great interest for researchers due to the high vulnerability that this region has to extreme weather events due to its geographical location (Orellana et al., 2009). In particular, the Yucatan Peninsula has been subject to studies on the occurrence of extreme weather events, mainly droughts and hurricanes and the impacts on agriculture (De La Barreda et al., 2020; Mardero et al., 2018; Mendoza et al., 2006) given the fact that rain-fed agriculture is one of the main sources of income for many communities in this region (Eitzinger et al., 2012).

2.5.1. Climate Variability

Climatic variability and its impact on the agricultural sector in the Yucatan Peninsula has been explored by different authors at different times. Garcia-Acosta et al. (2003) developed a catalogue of agricultural disasters based on the collection of information from historical drought events impacting the southeast part of Mexico for the period

1502-1899, which included the Yucatan Peninsula. The catalogue uses multiple sources and historical records in Mexico and reports on extreme events including droughts, hurricanes, hailstorms and frost and points out the major impacts caused in agricultural systems, mainly crop failure and food and water scarcity. This catalogue served as a reference for other studies wanting to understand the effects of past and present climate disturbances in the region. Mendoza et al. (2006) complemented that approach and analysed historical droughts to explore the periodicity and frequency of occurrence of such droughts through time series analysis. The evaluation was done considering the Yucatan Peninsula as a homogeneous region and the results showed that the occurrence of droughts in this region is different from the rest of Mexico and were mostly influenced by El Nino events (Mendoza et al., 2006).

Using a mixed-methods approach Mardero et al. (2018), found that there is an uneven distribution of climate trends (precipitation and temperature) within the Yucatan Peninsula, Mexico and its effects on agriculture. The quantitative approach included maize production data and climate variability analysis focused on climate trends and precipitation anomalies using data gathered from local weather stations for a 30-year period from 1981-2010. The qualitative analysis was done using semi-structured interviews. The results of the study showed that the trends in change in precipitation and temperature were different among the three Mexican states affecting crop production differently. They pointed out however, that this could also be influenced by local agricultural policies and by the soil characteristics of the region.

Climatic variability analysis has been also of great assistance to classify and develop maps of agroclimatic zones which can assist with planning in rainfed agriculture, particularly in Yucatan, Mexico where soils and precipitation patterns are important in determining the suitability of the land to support the growth of crops (Carranza et al., 2011).

Analysis conducted by De la Barreda et al. (2020) refined the available information on climate variability for the Mexican portion of the Yucatan Peninsula, by incorporating the spatial distribution of precipitation variability and drought occurrence by using statistical and geostatistical methods including cluster analysis, the standard precipitation index (SPI) and kriging. The study pointed out, through the development of detailed maps for a period from 1980-2011, that climatic variability in the Yucatan Peninsula in relation

to precipitation and droughts occurs in a non-homogenous way across different areas. The development of these maps is useful in areas where traditional rainfed agriculture is still regularly practiced and where adaptation of crop management is determined not only by climate patterns, but by crop varieties (Pinedo et al., 2009) and type of soils (Bautista-Zuniga et al. 2003, 2005).

Although these studies provide good insights into climate variability in the Yucatan Peninsula, there is a remarkable gap as most of them just considered the Mexican portion of the Yucatan Peninsula. Guatemala and Belize have been included in very few studies and those mostly for Guatemala (Hannah et al., 2017; Hidalgo et al., 2013). However, Belize has almost no information about these anomalies, so an analysis that includes this geographical portion of the Yucatan Peninsula would be very valuable.

2.5.2. Perceptions of climate variability and vulnerability

Several studies have been conducted aiming to understand how local societies build resilience to climatic disturbances and how they develop adaptation strategies. Studies using ethnographic data collection in several communities across the Yucatan Peninsula that have gathered information on the perception of local people about climate change and their response to climatic variability have shown similar impacts on crop yield and livelihoods, but with a differentiated severity across areas (Harvey et. al., 2018; Mardero et al; 2015; Metcalfe et al., 2020; Shmoock et al., 2013; Viguera et al., 2019) suggesting that different regional factors could influence the vulnerability of the population to these changes.

Vulnerability plays an important role in perception of climate variability and when assessing the severity of impacts from climate change (Donatti et al., 2019; Eakin, 2005) The IPCC has highlighted that the impacts of changing climate not only depend on how extreme single events are, but also on exposure and vulnerability, given the fact that these two elements “are dynamic varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors” (IPCC, 2012, p.7). This coincides with Morton (2007) discussion on how vulnerability of small-scale farmers in the tropics is not only associated with the geographical location, but with different demographic, socioeconomic and policy trends which can define the capacity of farmers to perceive and adapt to climate change. This argument was discussed more in depth by Monterroso-Rivas et al. (2018) who estimated

the vulnerability of people to climate change within different time periods using different variables within Mexico's agricultural sector. The authors considered exposure to climate change, sensitivity of agricultural activities to climate change and the adaptive capacity of people in three different time periods between 1990 and 2010. The results highlighted how communities are differentially exposed and vulnerable based on different social and economic indicators. In the case of Mexico, climate change exposure increased, and adaptive capacity was reduced within the time study period (Monterroso-Rivas et al., 2018). They concluded that vulnerability needs to be assessed by geographical area for better results.

This would mean that in a region as vulnerable to climate change as the Yucatan Peninsula, farmers that practice similar traditional farming systems can build resilience to extreme weather events differently based on their perception, exposure and vulnerability to certain local environmental, social, economic, cultural or political elements, therefore adaptation response is also different. This complexity between local environmental variability, perception, vulnerability and coping with changes in traditional farming is still an aspect not widely considered within the regional context when developing adaptation strategies by policymakers (Donatti et al., 2018).

2.6 Traditional Agricultural Systems in Mesoamerica: The *Milpa* Context

2.6.1. Defining the *Milpa*

Traditional *milpa*, also known as the “Mesoamerican Triad” is a polyculture and shifting agroecological system, in which, maize is planted together with beans and squashes in combination with many other crops like peppers, tomatoes, onions and even fruit trees like papaya or bananas (Teran and Rasmussen, 2009; Teran et al., 1998; See 1.4). The importance of this system rests on the fact that it not only represents a clear example of how multiple plant resources have been domesticated, but how the individual management of the plants is important to guarantee the success of the whole system to provide food security within the families that practice this cultivation system (Teran et al., 1998). *Milpa* systems can be found across all Mesoamerica and are cultivated in many ways under a biocultural approach depending on the region, and are managed depending on the microclimate, the type of soil, the traditional knowledge and needs of farmers (Hernandez-Xolocotzin, 1995; Teran et al., 1998). One of the biggest challenges that the modern traditional *milpa* system is facing is climate change (See 1.5) since farmers wait

for the arrival of the rains to plant and harvest. However, variable temperature and rainfall patterns can cause droughts or floods that destroy *milpa*'s production, threatening local food security (Santillan, 2014).

2.6.2. The origins of Maize and *Milpa*

Maize (*Zea mays*) is the main crop of *milpa* and was first domesticated in Mexico. The origin of modern maize has been debated, but there has been recognition of what could have been the genetic ancestor of maize: Teosinte (*Zea mays* ssp. *parviglumis*) which appears to have been cultivated first about 7, 000 years ago in the highlands of Central Mexico (Kato et al., 2009; Matsuoka et al., 2002). In the Yucatan Peninsula maize arrived around 5, 000 B.P. according to archaeobotanical records from Northern Belize (Colunga-GarcíaMarín & Zizumbo-Villarreal, 2004) and Mayan farmers spread its use across local landscapes turning it into the most important plant in Mayan Culture (Tuxill et al., 2010). Maize is considered the equivalent to wheat in the Old World and ancient records have shown that in Europe maize was called the “Turkish wheat” or “Turkish corn” (Staller & Carrasco, 2010). It is believed that this plant was domesticated through the traditional knowledge of ancient farmers across time which allowed them to develop a unique capacity for selecting and using the seeds to cultivate it year after year in different microclimates, soil conditions and in different geographical locations, evolving into different types of maize (Tuxill et al., 2010). Maize has a key role in the *milpa* system relying on multiple aspects and dimensions across cultures and places and because since its domestication its resilience has continued to be developed (CONABIO, 2011).

Maize is one of the most diverse grains as it can be cultivated at different altitudes and elevations depending on the region, the climatic conditions and the landraces (from below sea level to altitudes higher than 3000m; Sheikh et al., 2017), in cold or warm climates and different types of maize exist with different growing cycles from 2 to 13 months (Teran and Rasmussen, 2009). According to the Mexico's Commission for the Knowledge and Use of Biodiversity (CONABIO) it has been estimated that there are approximately 220 landraces of maize in Latin America. Mexico possesses the largest number of native landraces, approximately 64, of which 59 are considered native (CONABIO, 2011). The term landrace is used to group maize with shared phenotypic characteristics which has allowed 29% of all maize varieties to be identified as Mexican (CONABIO, 2011). There has been some debate around the use of the term ‘varieties’ to describe maize, as some authors and farmers believe this term should only be used when

the same seeds used in the cultivation cycle have the capacity to be used year after year and are selected from the harvest season. Hybrid seeds, despite being highly resistant to pests, are not considered maize varieties (Castanos, 2007). This is important to consider because much of the traditional knowledge associated with *milpa* is based in the use of certain maize varieties and soils and these at the same time are two elements that have been associated with climate change adaptation strategies within the *milpa* system.

2.6.3. Economic and Social Relevance of Maize and *Milpa*

Maize production is classified into two important categories: maize and green maize. Maize is the mature dry harvested crop that has multiple uses like food or for animal feed, while green maize is harvested fresh and unripe and used only as a fresh vegetable (Ortiz, 2007).

Economically speaking, maize is currently grown in more than 165 countries and is considered one of the most important grains across the globe. The Americas (36 %) and Asia (34 %) have the highest global maize areas, followed by Africa (21%) and Europe (9%). Half of the total maize produced comes from the Americas (49.6 %), followed by Asia (33.5%), Europe (8.8%), Africa (8%) and Oceania (0.1%; FAO STAT, 2022). The United States (349 M t pa) and China (277 M t pa) are the largest producers of maize. The rest of the countries include Brazil (109 Mt pa), Argentina (59 Mt pa), India (34 Mt pa), Mexico (27 Mt pa), Ukraine (26 Mt pa), Indonesia (23.5Mt pa), South Africa (16 Mt pa) and Russian Federation (16 My pa; FAO STAT, 2022).

In terms of the green maize produced globally, there are significant differences in comparison to maize. More than half of green maize production also occurs in the Americas (47.1%) followed by Asia (18.1%), Africa (18%), Europe (13%) and Oceania (3.8%). The two top producers of green maize are the United States (2.5 Mt pa) and Mexico (1Mt pa) followed by Indonesia (869, 000 t pa), Nigeria (780, 000 t pa), Croatia (766, 000 t pa), Peru (489, 000 t pa), South Africa (423, 000 t pa), France (413, 000 t pa), Thailand (387, 000 t pa) and Guinea (300, 000 t pa. FAOSTAT, 2022).

In Mesoamerica, maize is an important element of people's daily diet. In Mexico, maize consumed by people from rural areas represents 70% of their total consumption of calories and 60% of their total consumption of proteins, whereas in urban areas it represents 40% and 30% respectively (Castanos, 2007). Since maize in Mesoamerica is mostly cultivated together with other crops within the *milpa* system, the importance of

maize is high in the context of climate change since droughts are one of the main factors affecting national production (SIAP, 2017) but also because it is an important element of local food security and is socially and culturally relevant to many contemporary societies.

2.6.4. Cultural Relevance of Maize and *Milpa*

Maize is not only considered a staple food for people in Latin America, the Caribbean and Sub-Saharan Africa, but a central part of indigenous ritual practices and religious beliefs (González Jácome & Reyes Montes, 2015). A particular example of the cultural relationship between maize and societies has been documented in Mesoamerica where the development of civilizations such as Aztecs, Mayas, Zapotecas and Mixtecas is based on the cultivation of specific crops like maize using traditional farming systems and has been widely represented in their cultural manifestations and in traditions and practices extending back over millennia (CONABIO, 2011). Currently, modern Maya communities still have a strong cultural connection with maize and different studies have looked at this staple food in different countries from Mesoamerica and through many disciplines (Barrera-Bassols and Toledo, 2005; Santos-Fita et al., 2015; Schwartz and Corzo M., 2015). However, due to the impact that climate change is having on the Yucatan Peninsula, and the environmental, historical, social and economic elements associated with it, the need to study the complexity of this crop, has become more evident, particularly as the main element of one of the most ancient traditional farming systems: The Maya *milpa*.

2.7 The Traditional Maya *Milpa* System

2.7.1. Historical Context of the Maya *Milpa*

While food systems in the Yucatán Peninsula have transformed over the centuries, maize and *milpas* continue to play a vital role in the culture, economy, and daily life of the Maya people. (Tuxill et al., 2010). In the Mayan Culture, maize is represented in codices, murals, stone monuments and stories of Mayan Culture creation like the Popol Vuh (Staller and Carrasco, 2010). Since its arrival to the Yucatan Peninsula, Maya farmers have had a strong cultural, environmental and economic connection with maize and *milpas*.

Historical and contemporary records of *milpa* systems in the Yucatan Peninsula Region, have been described by several authors and have shown the complexity of this system (Bernsten and Herdt, 1977.; Ebel & Putnam, 2018.; Emerson, 1953; Hernández

Xolocotzi et al., 1995; Reina, 1967; S. Terán et al., 1998). According to Barrera-Bassols and Toledo (2005), the Maya *milpa* system is an interconnected system, not only because it provides food security and income to people, but because of the sacred value that maize has in contemporary Mayan culture, making it part of their social identity. In an extensive literature review conducted by the authors they highlight the uniqueness of the Maya *milpa* as “a flexible and dynamic knowledge-based strategy, constantly reshaped to cope with environmental and economic scarcities and uncertainties” (Barrera-Bassols and Toledo, 2005, p.22) and remarked on the complexity of the system highlighted in historical *milpa* descriptions, since different elements interplay in this system especially local ecological knowledge and biophysical features associated with it (Barrera-Bassols and Toledo, 2005) .

Faust (1998) found that due to the complexity of the *milpa* system, Maya Yucatec farmers assess biophysical characteristics of their land to choose which cultivation and management practices are better to put in place. Schwartz and Corzo (2015), conducted an extensive study on the *milpa* system in Guatemala, finding that contemporary milperos possess unique knowledge associated with the microhabitats of their plots, which played an important role in developing a capacity to adapt to uncertainties.

Two of the characteristics that have been considered in detail within this knowledge in historical and contemporary records, is related to maize varieties and soils. Lazos and Chauvet's (2011) social and biocultural analysis of the native maize landraces in Mexico. using ethnographic data, found that traditional farmers cultivate maize varieties based on four aspects: a) climatic resistance mostly to droughts; b) type of soil; c) biological resistance to pests and d) quality, flavour and characteristics for cooking maize dishes. In terms of the maize varieties, historical and modern descriptions have found that knowledge related to microenvironments and maize races is associated with specific management decisions and that the way maize is used in traditional farming systems in Mexico is influenced by its microenvironments and its capacity to adapt to environmental stressors (Nigh, 1976; Tuxill et al., 2010).

Tuxill et al. (2010) found that Maya farmers have developed a wide knowledge around varieties and make cultivation decisions about maize considering those individual varieties. The authors suggest that if researchers want to conduct studies of past and present elements of Maya *Milpa* systems it is important to “understand maize at the level

of varieties, particularly when analysing Mayan perceptions, representations, and decision making about maize” (Tuxill et al., 2010, p 468).

In addition to varieties, soils knowledge possessed by Maya Yucatec farmers is extensive and considered the most complex and complete among indigenous people in Mesoamerica (Barrera-Bassols and Toledo, 2005). Maya soil classification is different from the international descriptions since it is mostly based on the utility and potential in local land-management (Barrera-Bassols and Toledo, 2005; Bautista-Zuniga et al. 2005, 2010). Local knowledge associated with soils and varieties has been useful for farmers to classify soils, varieties and plot management practices. As a result, these biophysical characteristics, together with the land management practices, have been found to be part of the Mayan terminology to describe local soils in the Mexican portion of the Yucatan Peninsula (Arellano-Rodriguez et al; 1992, Bautista-Zuniga et al., 2003, 2010) and understand agricultural practices in the past and which are still used today.

2.7.2. The Intersection of Maya *Milpa* and Climate Change

In the context of the Maya *milpa*, the relationship between this agroecological system and climate is very strong, not only because it is mostly a rainfed system, but because of the association between local astronomical knowledge and local weather forecasts (Barrera-Bassols and Toledo, 2005; Teran et al., 1998).

The survival of ancient Mayan agricultural practices, including the *milpa*, despite their location in a geographical area with high vulnerability to extreme weather events (Orellana et al., 2009) and their diverse environmental conditions (De la Barreda et al., 2020; Mardero et al., 2018), has been explained by their capacity of adaptation developed through generations employing a multiple-use strategy and diversifying their resources to reduce risks and impacts from uncertainties (Barrera-Bassols and Toledo, 2005; Faust and Bilsborrow 2000). This tactic has been described in several historical and contemporary documents and researchers have suggested that government policies and local strategies should include these risk-reduction strategies in climate change policies since they are still part of the traditional practices of contemporary Maya farmers (Faust, 1998; Faust and Bilsborrow, 2000).

2.7.3. Power, politics and institutional frameworks in *milpa* and their relationship with climate change and knowledge systems.

One of the challenges that Maya *milpa* is currently facing has to do with environmental and socioeconomic problems and with the policies and political and institutional frameworks implemented within the agricultural sector. National governments across the Yucatan Peninsula region particularly in Mexico, have tried to modernise the *milpa* systems with imported international practices that are not compatible with the local conditions or the local knowledge systems. Similarly, government policies, programmes and support schemes are now being implemented focused on external market priorities, severely impacting small-scale farmers and their traditional practices (Faust and Bilsborrow, 2000; Keleman, 2010).

Maize prices in Mexico are currently paid under the cost of production due to the North American Free Trade Agreement (NAFTA). NAFTA is an agreement signed between Mexico, the United States and Canada which allows for free international trade, eliminating most tariffs on products. However, it is influenced by requirements and standards directed toward a specific type of market and intensive and mechanized agriculture. This has been reflected in increasing investments by transnational agribusiness, affecting small-scale farmers by replacing the local market economy with new market influences, but also resulting in degradation of soils (Faust and Bilsborrow 2000; Faust, 2001; Keleman, 2010). In combination with the effects of climate variability, these non-climatic stressors have challenged the way in which farmers in Mexico build resilience and adapt in the face of climate change, however maize farmers have persisted (Ebel et al., 2018).

Although the connection between power and politics in the face of climate change within agricultural systems is relevant, the way power dynamics shape the production, dissemination, and application of climate knowledge is still underexplored. Research on the influence of political agendas, neoliberal policies, and corporate interests on the framing of climate knowledge is an important gap. *Milpa* small-scale farming in the Yucatan Peninsula has and continues to evolve in the face of a changing climate, therefore there is a need to explore how other non-climatic stressors influence how resilience is built and how knowledge systems are impacted by this.

While there is growing recognition of the value of Indigenous knowledge in climate change adaptation, much of the literature still treats IK as separate from, or supplementary to, Western scientific knowledge. There is a need for more in-depth studies that explore the mutual enrichment and genuine integration of these systems in real-world contexts like in the context of traditional agricultural systems.

Current research often fails to address the power dynamics and challenges involved in combining these knowledge systems, particularly in policy and governance frameworks where traditional knowledge may be marginalized.

More empirical research is needed to explore how indigenous knowledge is operationalized within mainstream scientific and policy circles (Berkes, 2009; Ford et al., 2015). In addition, little has been done to examine the resilience of indigenous knowledge systems in the face of climate change (Nakashima et al., 2012) and how exactly climate change is influencing and reshaping knowledge systems.

The methods used in this study to explore the issues set out in this chapter are discussed in the following chapter.

Chapter 3. Methods

3.1 Introduction

This chapter describes the methodology used to address the research question and to achieve the aim and objectives of the research. The first sections are focused on detailing the framework of the methodology, followed by an explanation of the ethical implications of working with indigenous communities and indigenous knowledge and the researcher's positionality. Further into the chapter, a description of the research approach and design is given, including the description of the research sites, followed by a detailed examination of the data collection process and the methods used to analyse the information collected.

3.1.1 Framework for multiple knowledge integration in traditional farming systems through transdisciplinary research.

Social ecological systems are complex and studying them requires an integrated approach in order to fill gaps in knowledge (Burton et al., 2009; Miller et al., 2008). Academic research has worked towards filling knowledge gaps through the integration of several disciplines by using different approaches to describe such integration like cross-disciplinary, interdisciplinary, transdisciplinary, collaborative and multi-disciplinary (Stock and Burton, 2011).

Transdisciplinary research has been defined by Tress et al. (2005a, p.17) as “projects that both integrate academic researchers from different unrelated disciplines and non-academic participants to research a common goal and create new knowledge and theory”. It follows an approach on knowledge integration where “different knowledge cultures are bridged, and their knowledge fused together when answering a research question.” (Tress et al., 2005a p. 18) with knowledge that is equally valuable (Stock and Burton, 2011.)

Given the context of this study, the diversity and complexity of the social and natural elements present in the *milpa* system and because this project focuses on co-creating academic knowledge by understanding farmer's use and adaptation of different types of knowledge (indigenous and scientific) when building resilience to climate change, the present study was considered transdisciplinary (Miller, et al., 2008). By choosing this approach the research used both human and physical geography to understand the

valuable contribution of different forms of knowledge to climate science (Miller et al., 2008; Tress et al., 2005). The research was informed following a critical theory perspective around power-knowledge dominance (Akena, 2012); but also set out recommendations on how to better include different knowledges in climate science through the analysis of the relationship between local societies, history and knowledge production and adaptation (Chapter 2).

3.1.2 Epistemological Pluralism

Epistemology played an important role in this research as it helped to structure the contributions of both scientific and indigenous knowledge and the validity of the methods chosen for knowledge production (Miller et al., 2008). Considering these factors, the present research aimed to follow epistemic plurality to better understand the different ways in which knowledge systems are used to build resilience to challenges in local and complex traditional agricultural systems and how they are acquired, adapted and validated (Chapter 2; Section 2.1)

Epistemological pluralism (Healy, 2003; Miller et al., 2008) recognises four main aspects when researching issues from social ecological systems, and was chosen because it aligns with the purpose of this research:

- a. “Acknowledges the validity and value of multiple ways of knowing.
 - b. Integration of epistemologies turns into a better and more complete understanding of complex issues.
 - c. Accepts that operationalizing these different approaches may require continual negotiations.
 - d. Requires that disciplinary researchers work together to find ways to accommodate each other’s approaches rather than compromise them.”
- (Miller et al., 2008, p. 4).

In *milpa*, where the ecological and social aspects are linked (Barrera-Bassols & Toledo, 2005; Hernández Xolocotzi et al., 1995), epistemological pluralism can contribute to fully understanding the complexity of this interconnected system (Healy, 2003; Miller et al., 2008) involving knowledge of non-academic participants that are directly affected by an issue (Burton et al., 2009) and recognising that new knowledge (context-specific

or generic) can be derived from using different methods (e.g. mixed methods; Miller et al., 2008) disciplines (social and natural sciences) and local worldviews. This research was centred on engaging respectfully with indigenous individuals/communities to understand the use and adaptation of different types of knowledge by farmers when building resilience to climate change based on their own worldviews, their own priorities and their own knowledge of their territory.

The consideration of various environmental and social contexts in this research allowed the recognition of interrelationships when bringing together scientific and indigenous knowledge systems and the importance of valuing these equally to address challenges and reshape the way that modern globalised science (Western thought) has been historically applied by marginalising and/or dismissing different ways of knowing the world (Muller, et al., 2019; Rarai et al., 2020). Often modern globalised science is promoted as objective and universal under the rational-humanist framework (Muller et al.; 2019) and tends to be seen as superior from other worldviews from less represented cultures; consequently, dismissing indigenous worldviews but also creating knowledge separation (Muller et al., 2019).

Academic knowledge production relying only on modern globalised thinking is no longer adequate and it is necessary to acknowledge and recognise indigenous science and its epistemologies. Indigenous epistemology acknowledges a cultural group's ways of theorizing, constructing, encoding and passing knowledge (Watson-Gegeo et al., 1999). According to Gegeo & Watson-Gegeo (2001, p. 59) indigenous epistemology focuses on “the process through which knowledge is constructed and validated by a cultural group, and the role of that process in shaping thinking and behaviour” often through “traditional discourses anchored in culture”. Despite these arguments, indigenous views and knowledge are often separated from their own contexts, reducing them to perspectives or perceptions fitted into Western paradigms (Ellen & Harris, 2000). Recognising IK involves acknowledging different “ways of observing, discussing and making sense of new information” (Berkes, 2009). This research challenges this posture by recognising and valuing indigenous knowledge in the discipline of geography and integrating indigenous ways of being and knowing in climate change adaptation within the *milpa* system.

3.1.3 Indigenous knowledge in the context of academic research

In working with indigenous communities there are important issues to address and acknowledge. First, it is important to acknowledge the role that colonialism in the Global South has played in many of the narratives and discourses that members of indigenous territories have been and continue to be exposed to daily (Dedrick et al., 2023; Howitt, 2020). Accounting for colonialism effects is important and should be prioritised in the context of transnational scientific research to avoid replicating practices and discourses (L. T. Smith, 2021). By favouring and understanding the significance of Maya Yucatec indigenous knowledge, experiences, worldviews and incorporating social and spiritual settings to guide the present research, it was intended to break with traditional academic practices and offer a realistic decolonising approach to research (L. T. Smith, 2021). Although it is acknowledged that there are still many practices to challenge in working and collaborating with indigenous people, the research prioritised the principles of respect, consent, reciprocity, and shared opportunity which are fundamental principles of indigenous science (Muller et al., 2019). As a result, the research also includes a subchapter dedicated to the reflection process of learning and understanding indigenous knowledge in the context of scientific research and academic collaborations (See Chapter 7, Section 7.5).

3.2 Ethics

The present research was subject to review in accordance with the ethical guidelines from The University of Nottingham. Prior to visiting Maya Yucatec communities, a Research Ethics Form (See Appendix 1) was submitted reviewed and approved by the University of Nottingham School of Geography Research Ethics Panel in December 2019.

Given the nature of the research with regards to the use of traditional/indigenous knowledge, additional steps were taken to check if the proposed research activities were covered by any international official protective designation, particularly The Nagoya Protocol on Access and Benefit-sharing. A Nagoya Protocol Checklist for Researchers (see Appendix 2) was submitted and reviewed by the University of Nottingham Head of Research and Integrity in 2022 which determined that the present research does not fall into the Nagoya Protocol Scope and providing agreement that the research has followed the correct guidelines.

3.3 Positionality

An essential part of conducting research in collaboration with non-academic participants within indigenous territories is to reflect on the positionality of the researcher (Darwin Holmes, 2020). The researcher acknowledges that as a Latina women, her own family experience and cultural heritage as the granddaughter of a *milpa* farmer, has shaped her view of the world and might have influenced some aspects of this research; therefore this positionality statement was an attempt to become aware of her own biases for the purpose of reducing it (Braun & Clarke, 2013). Despite her own family heritage, she acknowledges her privilege in having had access to certain educational and professional resources that might not have been accessible to those who participated in this research. Having no direct agricultural background, the researcher is aware that she would never fully understand the worldviews and issues of farmers as she has not experienced those herself and does not identify as an indigenous person, nor belongs to the Maya Yucatec community. Giving her ‘lived familiarity’ with a priori knowledge of the Maya Yucatec people having worked in the research area for the past ten years, her gender, her ethnicity and race, her position throughout the research was looked at from a pluralistic lens and simultaneously as an insider and outsider (Mohammad, 2001); but operating as a learner and collaborator, recognising the role of farmers as mentors and the shared role on knowledge co-production between researcher and participants .

In conducting this research, the researcher also acknowledges that although every effort was made to integrate scientific and indigenous epistemologies the conceptualizations produced by the researcher throughout this study reflect her own perspective and interpretation of Maya culture and will never replace indigenous accounts of that culture. She also recognises that by having gained access to Maya Yucatec indigenous knowledge she acquired the commitment and responsibility of ensuring that this knowledge is protected and remains safeguarded in accordance to the Maya Yucatec peoples principles and any other institutional and international official protective guidelines.

3.4 Study Area

The Yucatan Peninsula geographical region was selected for this research. Specifically, the study focused on the *milpa* system practiced by indigenous Maya Yucatec people in six communities distributed along the State of Yucatan in Mexico and in the Corozal and Cayo Districts in Belize (Figure 3.1). The three Mayan communities in Yucatan,

Mexico included Maxcanu in Western Yucatan State, Tzucacab and Xoy in Southern Yucatan State and the three Mayan villages in Belize included San Antonio and San Jose Succotz in Western Belize and Patchacan in Northern Belize. This selection was done considering the reliance of these communities on seasonal agriculture for their livelihoods and self-subsistence, particularly maize cultivation, the impact of climate change events particularly droughts in traditional *milpas* within the last 10 years based on the National Standardised Precipitation Index (SPI), their land tenure and cultural background.

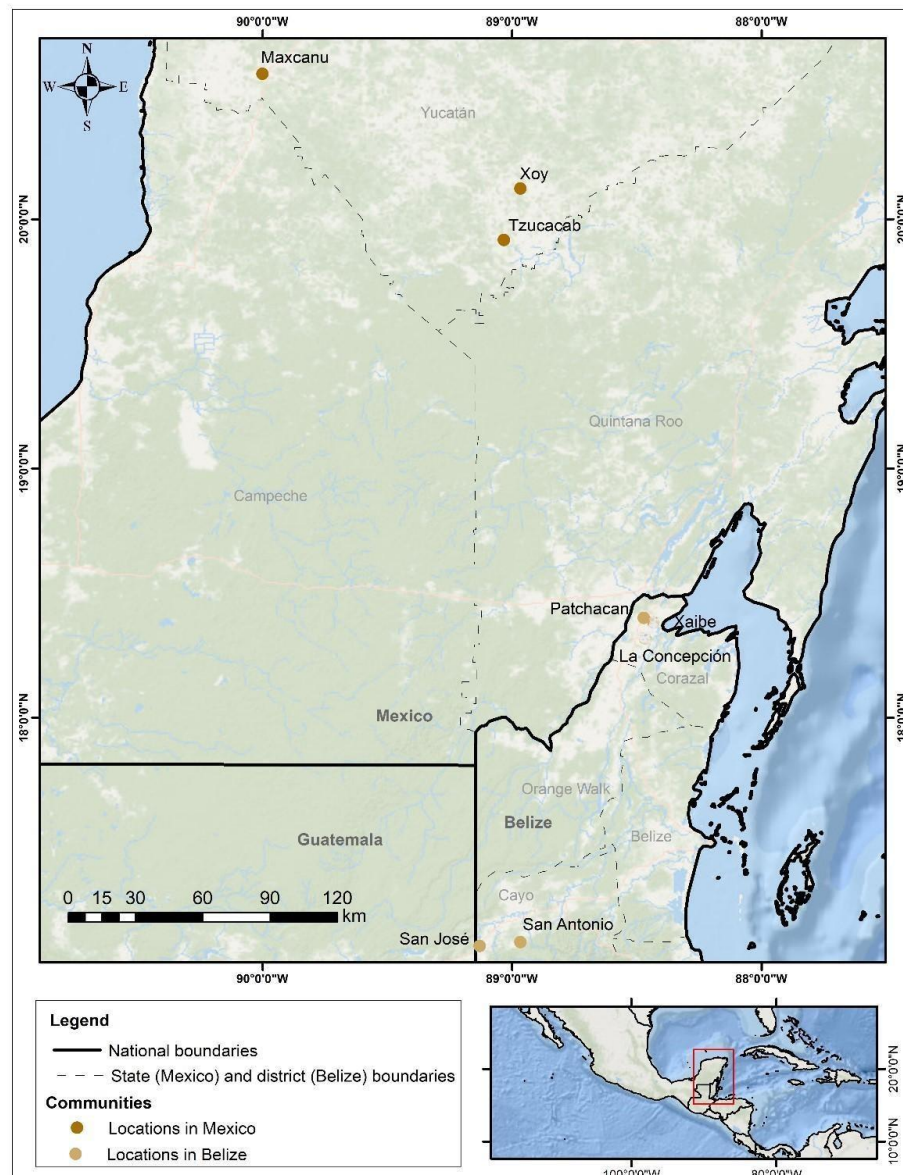


Figure 4.1 Locations of studied Maya Yucatec communities in Mexico and Belize

3.4.1 Description of research sites

3.4.1.1 Yucatan, Mexico

The Yucatan State is in the southeast part of the Mexican Republic, within the northern part of the Yucatan peninsula region. It is limited to the north and west by the Gulf of Mexico, to the southeast by the state of Quintana Roo, and to the southwest by the state of Campeche. Most of its topography is flat and formed of calcareous rocks (Gobierno de Yucatan, 2020). It occupies 39,524 km² and it is divided into 106 municipalities with an estimated population of approximately 2,320,898 of which 23.70% speak an indigenous language (INEGI, 2020). At the federal level Yucatan is considered a state with a high index of marginalisation and 47.8% of the state population is considered impoverished (BIENESTAR, 2023). In terms of poverty related to food insecurity, 39.7% of the state population is considered to have food insecurity, with 19.8% considered to have a moderate or high level of food insecurity (CONEVAL, 2020).

Although the Yucatan State has a wide range of economic activities, agriculture is still important for many communities, particularly for indigenous ones, as it is used for self-subsistence. This has been shown in the current land management statistics as 81.3% of the state land is under seasonal management. The most important annual crops cultivated are maize (white and yellow), squash, soy and watermelon (INEGI, 2022). The diversity of crops cultivated across the state is determined by the different types of soils and climate variability present across the state, therefore these two aspects are key determinant in the agricultural sector and were considered as part of this research. The state has recorded 12 types of dominant soils according to the World Reference Base (WRB) with Leptosol (LP) being the dominant soil present in 51.79% of the state surface, followed by Phaeozem (PH) with 13.43%, Luvisol (LV) with 11.93% and Cambisol (CM) with 9.26%; the rest of them each cover less than 3% of the state surface and include Lixisol, Solonchak, Vertisol, Regosol, Nitisol, Chernozem, Histosol, Gleysol, and Arenosol (INEGI, 2021).

The Yucatan state has an annual average temperature between 25.1°C and 26.7 °C. Fifty-five percent of total annual precipitation comes in summer (June to October). Precipitation varies from 529.6 mm in the northwest to 1,289 mm in the south (INEGI, 2021). Overall, the Yucatan Peninsula, has three main sources of rain throughout the year which are associated with the north-east trade winds, tropical storms and hurricanes in

the summer/autumn and with *nortes* (cold fronts) in the winter. Summer is the main rainfall period and winter is dry. There is an intra-summer dry period also called *canicula*, which occurs from the end of July to August (40 days) and the driest period occurs from March until June.

3.4.1.2 Maxcanu

Maxcanu is a municipality located in the western portion of the Yucatan State (20°35'06.214" N 90°00'02.305" W) covering an area of 1,320.82 km² and at an average altitude of 10 meters above sea level. Its population is approximately 24, 796 people (BIENESTAR, 2023a) where 36.55% speak an indigenous language (INEGI, 2020). Despite their proximity to the state capital, Merida (62 km), it is considered a highly marginalised municipality where 57.3% of the population is under moderate (48.3%) and extreme (9.0%) poverty (BIENESTAR, 2023a).

The municipality average annual temperature is from 26-28 C° and an average annual precipitation of 700-1100 mm (INEGI, 2010). The types of soil present in the municipality are Leptosol (70.52%), Luvisol (17.49%), Regosol (8.59%), Histosol (1.39%), Solonchak (0.69%) and Cambisol (0.54%) (INEGI, 2010a). Maxcanu has a long history in terms of agricultural activities, having been the national producer of jicama (*Pachyrhizus erosus*), a tuberous root or yam bean originated in Mexico and widely consumed across the country. Maxcanu is still considered an agricultural community where crops are mostly cultivated under seasonal manual agriculture (37.63%) vs mechanized (1.65%) and managed under *ejido* land tenure (communal land which tenure is written under the Mexican agrarian laws). The main crops cultivated besides jicama are maize (under *milpa* system), habanero chili, aloe vera and papaya (INEGI, 2015)

3.4.1.3 Tzucacab

Tzucacab is a municipality located in the southwest corner of the Yucatan state (89°03'01.189" W 20°04'18.954" N) covering 767.827 Km² at an altitude of 31 meters above sea level. It has an estimated population of 15,956 inhabitants (BIENESTAR, 2023b) with 46.75% speaking an indigenous language (INEGI, 2020). It is considered a highly marginalised municipality where 83.4% of the population is under moderate (55.9%) and extreme (27.6%) poverty (BIENESTAR, 2023b).

The municipality average annual temperature is 24-28 C° and the average annual precipitation is 1000-1200 mm. In terms of the soil composition Tzucacab has a diverse range of soils including Luvisol (42.97%), Vertisol (22.01%), Phaeozem (19.66%), Leptosol (14.43%) (INEGI, 2010b). In Tzucacab 76.09% of the municipality is still forested, 26.79 % of the land is used for seasonal agriculture, while 27.64% is used for mechanized/continuous and land tenure is also under ejido (INEGI, 2010b). The main crops cultivated in Tzucacab are citrus, maize (under *milpa* system) and vegetables.

3.4.1.4 Xoy

Xoy is an *ejido* located within the Peto municipality in the southwest part of Yucatan State (20°07'24.656" N 88°58'17.510" W) at an altitude of 29 meters above sea level. The community has 725 inhabitants and 99.30% of its population is formed by indigenous people of whom 41.79 speak an indigenous language (INEGI, 2020). The main economic activity in Xoy is agriculture and maize is the major crop, cultivated under the *milpa* system and the main source of income. Other economic activities include raising livestock and elaboration of hand crafts. Xoy is considered an area vulnerable to droughts, floods and forest fires (INEGI, 2015). Xoy's average temperature is 24-28 C° and has an average annual precipitation 1000-1300 mm (INEGI, 2010c).

3.4.1.5 Belize, Central America

Belize is a country located on the Caribbean coast of northern Central America in the south-eastern corner of the Yucatán Peninsula lying between latitudes 15.75° and 18.50° North and longitudes 87.50° and 89.25° West (National Meteorological Service, 2024). It shares borders with Quintana Roo, Mexico in the north, with Guatemala in the south and west and with the Caribbean Sea in the east. It was known as British Honduras until 1973 and was the last British colony on the American mainland. The country has an area of 22,967 km² and a length of approximately 260 km from north to south and 180km from east to west. Belize is part of the Mesoamerican Biodiversity Hotspot, as fifty percent (50%) of the territory is covered by tropical forest and holds a diverse range of terrestrial and marine ecosystems (Government of Belize, 2020).

Belize's topography is divided into two main physiographic regions. The first one is the Maya Mountains/Mountain Pine Ridge massif with a maximum elevation of 1124 meters above sea level, which includes well drained basins and plateaus. The second one is the northern lowlands with an elevation of 250 meters above sea level and the southern

coastal plain with elevations of less than one meter and characterized for having poor drainage (National Meteorological Service of Belize, 2024). Soils are highly influenced by this topography and drainage and have been classified according to Belize's topography. The geology is mainly formed by different types of limestone, most of the country is formed mostly by granite and other Paleozoic sediments. The Maya Mountains are quite distinctive from the rest of the country as they are formed from Cretaceous limestone characterized by a karst topography which is noticeable in the form of caverns, sinkholes and underground streams (Bateson and Hall, 1977).

Belize's climate is described as subtropical in northern Belize and becomes tropical in the southward part of the country. It is characterized by only having a rainy and a dry season compared to Mexico. (See 3.4.1.1) and separated by a cool transitional period. The rainy season normally occurs from May to November, interrupted by a short dry season from August and September; whilst the dry season occurs from February and April and the cool transition period from November through February. The average annual rainfall varies from 1500 mm in the north to 3800 mm in the south; and the average temperature fluctuates from 27°C along the coast to 21°C in the hills. Lowest temperatures are mostly registered in January, while the highest temperatures are registered in May (National Meteorological Service of Belize, 2024).

Belize's estimated population in 2019 was 408, 487 (SIB, 2020). The country of Belize is formed by six districts: Corozal in the north, Orange Walk in the north-west, Belize in the east, Cayo in the west, Stann Creek in the south-east and Toledo in the south, nine municipalities and approximately two hundred forty villages.

Across the country seven different ethnic groups have been recognised: Creole, Garinagu or Garifuna (African slave's descendants), Mestizo (mixed Mayan and Spanish), Maya (Kechi, Yucatec, and Mopan Maya), Mennonites, Asian, Caucasian and East Indian. Belize's official language is English, although Spanish, English and Creole are the most popular languages spoken across the country (SIB, 2020). The Belizean economy is small with a Gross Domestic Product (GDP) of \$1.871 US billion dollars in 2018 (represents less than 0.01 percent of the world economy), compared with Mexico whose GDP value was \$1.221 trillion US dollars in 2018 (World Bank, 2020).

Belize relies mostly on international trade, however there are two critical sectors that make major contributions: agriculture and tourism. Agriculture in Belize is an important sector economically contributing in 2021 to approximately \$590 million annually to economic output which represents 80 % of domestic exports, but also socially, as 17.9% of the labour force are employed in agriculture (MAFSE, 2021). It is critical for the development of the country as it provides economic growth, employment and income, foreign trade earnings and food security (CIAT-World Bank, 2018). Overall, rice, maize (cultivated under *milpa* system), beans and livestock are the basis of Belizean's diet and local income.

Belize is considered a self-sufficient nation and food secure in staple foods in terms of production but suffers food insecurity from a social perspective due to issues related to access and distribution of products. The country has high levels of poverty, with 41% of the population living below the poverty line (CIAT-World Bank, 2018). Due to the geographical location of the country the impacts of climate change and extreme weather events make agricultural systems one of the most vulnerable and critical to food security (Caribbean Community Climate Change Centre, 2014).

3.4.1.6 Cayo District, Western Belize

Cayo District is the largest district in Belize covering approximately 5196 km² and has an estimated population of 105,190 inhabitants (SIB, 2021). The topography of Cayo district varies within short distances and includes tropical forest, hills, pastureland and rivers. It is also home to some of the most important Maya archaeological sites and home to Maya Yucatec descendants. Cayo produces much of the country's agricultural and dairy products. Agricultural production includes traditional maize (through *milpa* system), vegetables, bananas and citrus. The Mennonite farming community dominates most of the poultry and dairy markets along with maize, beans and vegetables and are the main competitors of other small-scale farmers. Despite this 48.6% of the inhabitants suffer moderate food insecurity while 4.7% suffer severe food insecurity (FAO, 2021). In terms of poverty Cayo has the second highest poverty rate in the country with about 52% (SIB, 2018).

3.4.1.7 Corozal District, Northern Belize

Corozal District is the smallest district in Belize and covers approximately 1, 860 km² and has an estimated population of 51, 561 inhabitants mainly Mestizos (SIB, 2021). It is also home to one of the largest populations of Maya Yucatec descendants in the country given that thousands of them fled to Corozal and become farmers after Mexico's Caste War (a rebellion of the Maya people in Yucatan against white and mestizo elites oppression that begun in 1847; Bolland, 2004). Agriculture has historically been important for Corozal mostly because of its dependency on sugar cane. In terms of food insecurity about 51.1% of the inhabitants suffer of moderate food insecurity, while 4.6% suffer of severe food insecurity (FAO, 2021). In terms of poverty Corozal has the lowest poverty rate in the country of about 45% (SIB, 2018).

3.5 Research Approach

A review of past and current methodologies around the study of the *milpa* system was done to narrow the methodological approach of this study. In doing so, historical and contemporary descriptions and records were initially reviewed to select the main study variables and protocols to collect data. Records and descriptions included four in Yucatan State (Emerson, 1935; Hernandez-Xolocotzin, 1995; Landa, 1566; Teran and Rasmussen, 1994) and one in Belize (Bernsten and Herdt, 1977).

The first one, Landa's (1566) review is considered a key document to understand Maya culture during early colonial times in Yucatan Mexico, which provides descriptions of the history, way of life (including *milpa* agriculture and relevance of maize) and religious beliefs of the Maya people and was useful to track variables that have been relevant for farmers across time. In addition, a preliminary and informal survey conducted by Emerson (1953) and preserved in the *Annals of the Missouri Botanical Gardens*, was also reviewed and showed a detailed description and study of the *milpa* system practiced by the Maya people of Yucatan Mexico and which is known for having set the basis for later formal and modern studies of this system. Emerson's study employed two well-known methodologies currently used in social sciences: participant observation and surveys; and provided a detailed description on microenvironments, focusing particularly on two specific aspects that are important to understand the resilience of the *milpa* system across time: soils and climate. This description aligns with that of Teran and Rasmussen (1994) and Hernandez-Xolocotzin (1995), however, these two other studies also consider maize and crop varieties as important elements of study in the *milpa*. Bernsten and Herdt (1977)

conducted a study in Belize around the *milpa* system which is considered one of the few reliable descriptions for the country. In this study the authors used surveys and participant observation to describe and understand the *milpa* system practiced by Yucatec Maya farmers in Western Belize and the potential development of the agricultural sector within the country. There are three additional elements well described as part of the study besides the *milpa* management: traditional ecological knowledge, marketing opportunities, and impacts on both livelihoods and food security.

Together these studies compile a set of indicators that have played a significant role in Maya Yucatec peoples' lives across time and which were considered relevant in the context of this research to understand what farmers consider and prioritize when building resilience to climate change. These indicators are soils, climate, maize and crop varieties, indigenous knowledge, marketing, livelihoods, food security and religious beliefs/worldviews. Considering the influence that agricultural policies have played in the *milpa* system across time, this indicator was also included in the present study. Few modern studies have fully incorporated and studied all these indicators; therefore, this research incorporated and linked these indicators to maximize data collection across the research under multiple contexts (Eakin and Luers, 2006).

3.6 Research Design

3.6.1. Knowledge integration through Convergent Mixed Methods

Study of traditional agricultural systems like *milpa* involve different scientific approaches and methods (Nuijten, 2011). However, since it also involves non-academic knowledge (indigenous knowledge) it was necessary to find better ways of integrating, preserving and optimizing this knowledge in response to uncertainties (Gómez-Baggethun and Reyes-García, 2013).

Considering the complexity of the *milpa* system and of agricultural systems in general (See Chapter 2; Barrera-Bassols & Toledo, 2005; Nuijten, 2011) a convergent mixed methods design (Creswell, 2015; Figure 3.2) was used to collect both qualitative and quantitative data, which were analysed separately and then merged to obtain an integrated view about the current state of the Maya Yucatec *milpa* system from both a community and individual perspective with case studies in two different countries considering environmental, social and cultural aspects, and integrating both scientific and indigenous knowledge.

The convergent design was particularly useful to explain convergences or divergences between case studies, communities and across-countries in relation to what environmental, socio-economic and cultural aspects Maya Yucatec people currently prioritize when practicing *milpa* and how knowledge is used and adapted based on those priorities and on specific factors when building resilience to known and unknown challenges (Creswell, 2015).

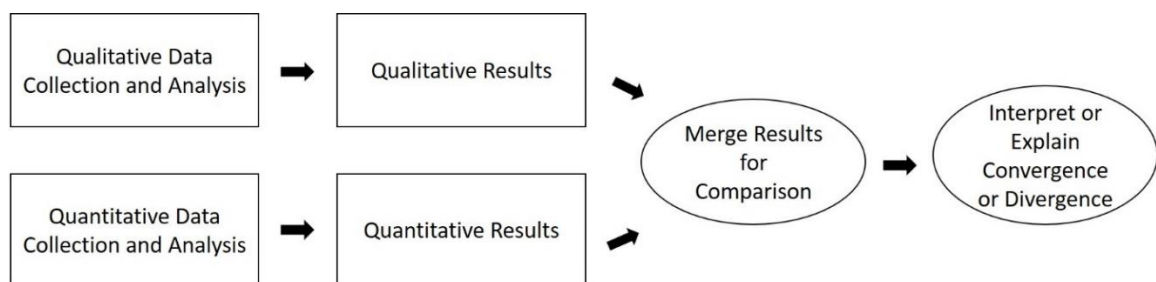


Figure 4.2 Convergent design (Creswell, 2015).

3.6.2 Pilot Stage

The research started with a pilot phase in January 2020 in order to gain perspective on farmers' worldviews and priorities around the *milpa* system and interests and concerns in climate science. The pilot phase allowed for identifying the elements and concepts of mutual interest for the research and for farmers and to formulate the appropriate data collection methods.

3.6.2.1 Pilot interviews

Pilot interviews and initial consultation and meetings with Maya indigenous farmers and farming groups, local researchers in Mexico, and administrators and agricultural officers in Belize, were conducted between January and February 2020 to get a better scope of the local agricultural sector.

For the first stage of the research, purposive sampling (Patton, 2002) was used to select and conduct a total of 21 interviews (18 farmers and 3 farming groups; Table 3.1) across eight different communities that still practice *milpa* to gain a general insight into their overall knowledge and worldviews around *milpa*, as well as their *milpa* management, livelihoods and farming activities.

Table 4.1. Summary of the interviews conducted during the pilot visits in 8 communities in Mexico and Belize.

Location	Interviews conducted	Ethnicity of Interviewees	Type of Farming
Maxcanu, Yucatan Mexico	4 Farmers	Maya	Traditional. Semi-traditional and mechanized
	2 Farming Groups	Maya	Traditional and Semi traditional
Xoy, Yucatan, Mexico	1 Farming Group	Maya	Traditional
Tzucacab, Yucatan, Mexico	2 Farmers	Maya	Traditional
Xaibe, Corozal, Belize	2 Farmers	Maya	Traditional and Mechanized
La Concepcion, Corozal, Belize	3 Farmers	2 Salvadorian and 1 Mayan	Traditional and Mechanized
Patchacan, Corozal, Belize	1 Farmer	Maya	Semi-traditional
San Antonio, Cayo, Belize	5 Farmers	4 Mayan, 1 Guatemalan	Traditional, semi traditional and Mechanized
San Jose Succotz, Cayo, Belize	2 farmers	1 Mayan, 1 Guatemalan	Traditional and Semi traditional

Pilot interviews were conducted in Spanish or English based on the farmer's language preference. Although interviewees are Maya descendants, or identify themselves as Mayan, not all farmers speak Maya and the language frequently spoken is either English or Spanish (in the case of Belize) and Spanish (in the case of Mexico), hence interviewees were given the option of conducting the interview in either one language or the other. However, consideration was also given to the Maya language, to farmer's cultural background and to the local governance and community protocols. Therefore, in some cases, a gatekeeper accompanied the interviews for translation and/or explanation of specific Maya terms when necessary. Gatekeepers also helped to contact potential farmers that could fit the criteria for participation in the study when needed. In addition, the researcher also learned Maya Yucatec terms and expressions to facilitate the engagement process throughout the research.

Prior to the interview, a short explanation and a written copy of the purpose of the research was given to farmers (including how data would be used and stored and the

informant's rights), followed by written consent and approval to conduct and audio record the interview. Notes and a voice recorder were used to support the interviews. Data were stored in the O365 protected university storage system and in an external hard drive encrypted with a password only accessible by the main researcher. Pilot interviews were analysed using an interpretive thematic analysis (Creswell, 2018) which further allowed the design of interviews and surveys to be improved for future visits, as well as to select multiple case studies.

3.6.3. Participant recruitment: Selection of Multiple Case studies

The purpose of using a multiple case study (Creswell, 2018; Creswell et al. 2007; Yin, 2003) was because there is no unique way of “doing *milpa*”; as a result, *milpas* can be practiced differently and the elements present can vary from one farmer to another (Barrera-Bassols and Toledo, 2005; Hernandez-Xolocotzin, 1995). This design was then used to ensure that different views of farmers about the *milpa* system were considered and assessed.

According to Creswell et al. (2007, p. 246) a multiple case study involves “selecting one problem and purposefully using multiple cases to illustrate different perceptions of the issue”. Trying to understand only one way of doing *milpa* would not allow full understanding of the many ways in which this system and the knowledge embedded in it is viewed and therefore adapted. This aligns with Stake's (2000; 2005; 2006) case studies approach aiming to search for the multiple perspectives of those involved in a specific case (e.g. the *milpa* system) in order to gather collective and distinctive views of what is occurring within the *milpa* in a changing climate.

The pilot visits allowed eight case studies to be identified (Table 2) that could represent the variety of the *milpa* system (context-specific) within different areas of the Yucatan Peninsula. Criteria for selection of case studies was guided by the following:

- Participants are Maya descendants and identify themselves as members of the Maya Yucatec cultural group.
- Participants still practice *milpa* in a traditional or semi-traditional way.
- Participants are proficient and comfortable speaking Spanish, the native language of the primary researcher or English, the second main language of the primary researcher.

The four cases within Mexico and within Belize were also locally different from each other and were also purposefully selected that way in order to do local cross-case comparison as part of the convergent mixed methods design (See Section 3.1).

Table 4.2. Case studies selected per country (Mx = Mexico, BZ = Belize) for this research

Case study	Community	Land management	Crops associated	Land tenure	Irrigation
Farm1-HST	Oxkintok-Maxcanu MX	Intercropped	Beans	Ejido (Communal Group)	Rainfed
Farm2-LM	Oxkintok-Maxcanu MX	Intercropped	Beans and Squash	Ejido (Communal Group)	Rainfed
Farm3-LNXY	Tzucacab, MX	Intercropped	Squash	Ejido (Communal Group)	Rainfed
Farm4-LGR	Xoy, MX	Intercropped	Beans, squash and Sweet potato	Ejido (Communal Group)	Rainfed
Farm5-HY	San Antonio, BZ	Rotation	Vegetables	Cooperative	Rainfed and Irrigation
Farm6-LY	San Antonio, BZ	Rotation	Vegetables	Family	Rainfed and Irrigation
Farm7-HY	San Jose Succotz-Calla Creek, BZ	Continuous	Monoculture	Family	Rainfed
Farm8-HL	Patchakan, BZ	Rotation	Vegetables	Cooperative and Family	Rainfed and Irrigation

3.7 Data Collection

Following Yin (2003), practices for collecting data through multiple sources (included but not limited to interviews, documents, participant and direct observations and physical instruments), two datasets (one qualitative and one quantitative) were structured to collect data regarding the *milpa* system. Fieldwork visits were completed between 2020 and 2023 in six communities in Yucatan State and in Belize (See Fig 3.1) for the purpose of collecting the type of data allocated to each of the research datasets). In Yucatan State one community was in the west (Maxcanu) and two in the south (Tzucacab and Xoy). In Belize, two communities were located in Western Belize (San Antonio and San Jose Succotz) and one in northern Belize (Patchakan). For each dataset, multiple sources were used (Yin, 2003) including eight semi-structured interviews, participant observation in

eight *milpa* plots, 35 surveys and two community workshops (one in Maxcanu, Yucatan Mexico and another one in Central Farm, Cayo District Belize).

The first dataset comprised gathering qualitative information around cultural views, knowledge, biophysical characteristics, priorities and constraints and adaptation strategies involved in the management of *milpa* through the selection of multiple case studies (see Chapter 5; section 5.2). Because *milpa* is practiced individually, but community social networks play a crucial role in Maya Yucatec life, information on cultural views, knowledge, biophysical characteristics, priorities and constraints and adaptation strategies were also documented at the community level through surveys.

The second dataset comprised quantitative data that assessed local environmental conditions and agro-ecological management practices for each of the case studies and data was used to understand the relation of environmental variables impacted by climate change with cultural views, priorities, constraints and knowledge systems (Figure 3).

Once information was collected for each data set, data were brought together, compared and integrated to explore differences and similarities and their variability across cases, communities and countries (Creswell, 2007; Lauckner, et al; 2012; Yin, 2003). By using this data collection protocol it was possible to gather and link different farmer's views, priorities, constraints, and management activities within the *milpa* system and the various contexts in which knowledge is used and adapted to build resilience to the impacts of climate change and to other unknown challenges (e.g. Covid-19). In doing this integration of both indigenous and scientific knowledge was completed.

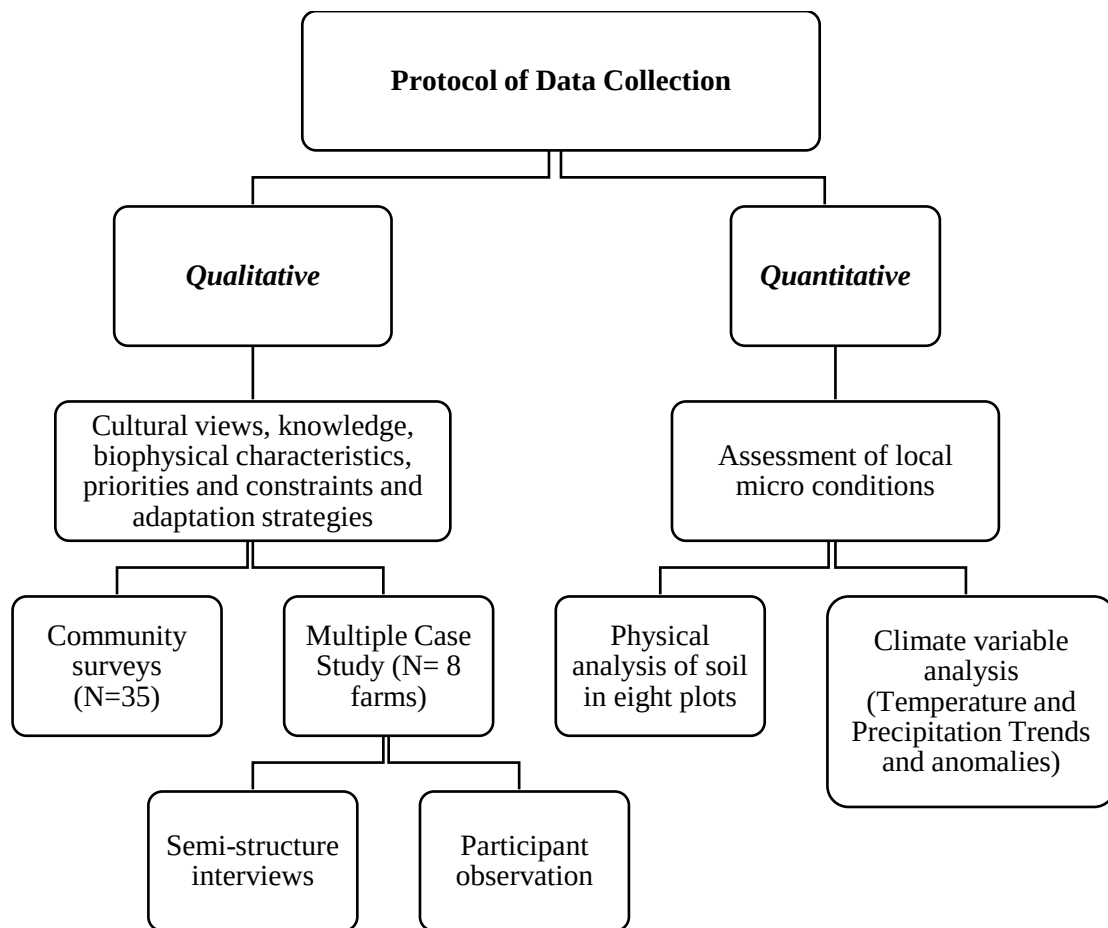


Figure 4.3. Description of the protocol for data collection including the data set and sources used.

3.7.1. Qualitative Dataset

3.7.1.1 Interviews

A total of eight in depth semi-structured interviews (See Appendix 3) were conducted with eight male farmers aged between 35 and 75 years old. Interviews were conducted in September 2021; four in Mexico (two in Maxcanu, one in Tzucacab and one in Xoy) and four in Belize (two in San Antonio, one in San Jose Succotz and one in Patchakan). Informed consent was given by all farmers and authorization for recording the interview and taking pictures was granted prior to conducting the interview. Interviews were designed both in English and Spanish, however all were conducted in Spanish according to farmer's choice and lasted approximately 90 minutes each. Each interview consisted of thirty-seven questions split into eight sections. Interviews were conducted either at the farmer's house or *milpa* plot based on their choice.

3.7.1.2 Surveys

A total of 15 surveys per community (90 surveys in total) were planned to be conducted within the six research study sites (Maxcanu, Tzucacab, Xoy, Patchakan, San Antonio and San Jose Succotz) in September 2021. Due to Covid-19 restrictions, it was only possible to conduct six surveys per community, except in San Jose Succotz, where one farmer cancelled last minute, and only five surveys were conducted. Therefore, a total of 35 surveys were conducted for this study. Informed consent was granted by each farmer prior to conducting the survey. Permission for taking pictures was also requested at the beginning of each survey.

All surveys consisted of sixty-three questions divided into six sections and were designed in English and Spanish but conducted in Spanish at the farmer's house and lasted approximately 45-60 minutes (Figure 3.5).

A total of 35 farmers, aged between 30 and 80 years old, took part in the surveys. Although *milpa* has been a farming system predominantly dominated by males, in some of the communities it was found that women are currently practicing this activity. Therefore, the community surveys included female (n=6) and male *milpa* farmers (n=29).



Figure 4.4. Surveys conducted in 2021 with Maya farmer in the community of San Antonio in western Belize (top) and Maya priest (x-mjen) and farmer (bottom) in the community of Patchakan in Northern Belize.

3.7.1.3 Participant Observation

In order to understand better farmers' positions and views in relation to the *milpa*, participant observation was conducted in eight *milpa* plots (case studies) in September 2021 (a short visit on the day of the interviews and a full day visit when the soil sampling was completed) followed by a third visit in January 2023. The process involved accompanying the farmer to his *milpa* and engaging in *milpa* farming activities while taking field notes on behaviour and activities and asking general questions for farmers to

freely provide their views while also conducting their everyday activities (Creswell, 2018). Prior to engaging in participant observation, the researcher asked permission and verbal consent from the farmer and fully explained the settings, as well as the process of interaction occurring, while conducting participant observation.

Since farmer's income depends on everyday labour at their farm and in order to respect farmers' time and minimize the impact of the research activities in their job, the researcher role was as an active participant rather than just an observer. In doing this, it was intended to mitigate any power dynamics that could emerge from the process. Participation allowed for active learning how milpa is done and understand more in-depth the individual management while compiling additional views and narratives to those recorded in the semi-structured interviews which facilitated the interpretation of the data collected across the study.

3.7.2 Quantitative Datasets

3.7.2.1 Local Environmental Conditions

3.7.2.1.1 Soil Sampling

A total of eight farms, four in Mexico and four in Belize were visited and sampled in September 2021. Soil samples were taken from the 0–14cm soil layer of each of the plots (Figure 3.6). A composite sample (subsample) per field was obtained by collecting 15 samples of soil from the same plot and mixing them thoroughly in a bucket to give a total of eight composite samples. In addition to sampling cultivated areas, samples from adjacent forest/non-cultivated areas surrounding six plots (Farm 1, 3, 4, 5, 7 and 8) were also taken following the same process as described above. In the case of large forest/non-cultivated areas sampling was done taking samples along the shape of an imaginary “W”, covering a similar area as the cultivated plots (Palintest Manual, 2019). Two of the studied plots were in zones with no adjacent non-cultivated areas therefore only six samples were taken. Samples were stored in plastic bags, tagged and imported into the UK following DEFRA's guidelines under license 122259/298059-0 with the assistance of in-country collaborators. Samples were deposited into the School of Geography's Geosciences Laboratory.



Figure 4.5. Soil sampling in a *milpa* plot in the community of San Jose Succotz in Western Belize.

3.7.2.1.2 Meteorological records and microclimates dataset

In 2020 two Davis Vantage Pro WeatherLink meteorological stations were installed in Maxcanu and Hobonil (Tzucacab) to monitor microclimatic conditions (Figure 3.7). The purpose of this monitoring was to be able to compare records from these stations with those provided by the Mexican National Meteorological Service stations in Yucatan or to gather data given the lack of information from government institutions. Unfortunately, throughout the study the two stations were impacted multiple times by extreme climate events leading to complete data loss.



Figure 4.6. Meteorological stations installed in Hobonil (Tzucacab; left) and b) Maxcanu (right) in Yucatan Mexico during 2020.

Weather data from the National Meteorological Service in Mexico (CONAGUA) and Belize (NMS) was obtained between 2021 and 2023 from four meteorological stations located closest to the studied plots. Three meteorological stations were considered for this study given the reliability of the data. Two of the stations were in Belize, one in the north in Libertad town (14 km from Patcahakan) and the second one in western Belize in Central Farm (22 km from San Antonio and San Jose Succotz/Calla Creek). In Mexico, one of the stations was in Peto (8 km from Xoy) and the second station in Maxcanu but this was found to be inactive since 2000 and therefore not included in this study. Information obtained from the three stations included mean annual temperature (average, maximum and minimum) and precipitation and covered a period of 30 years (1991-2021).

3.8 Data analysis

3.8.1 Qualitative Dataset

3.8.1.1 Interviews

Information collected from interviews was transcribed in Spanish and further analysed through a reflexive thematic analysis (Braun and Clarke, 2022) which involved six analytic phases (Table 3.4). Reflexive thematic analysis is a theoretically flexible interpretative approach that facilitates the identification and analysis of patterns in a data set and considered a useful resource for knowledge production (Braun and Clarke 2024). Given the nature of the research and the cultural group associated to it, this analysis proved to be very useful for intersecting farmer's worldviews with science. Since *Maya* terms emerged during the data collection and were used interchangeably with Hispanic terms it was decided that the thematic analysis was done in Spanish to maximize the results of the analysis and avoid loss in translation (compared to transcribing and analysing in English).

Table 4.3. Phases of reflexive thematic analysis for interviews conducted in Mexico and Belize (Adapted from Braun and Clarke, 2024).

Phase	Description
Data familiarization	Audio recorded interviews were organized and given a specific ID. Then they were transcribed in Spanish. Transcripts were organized in a word document by country and by community. Transcripts were read individually several times to get familiar with the stories and initial notes were taken.
Data coding	Transcripts were re-read individually, and notes were taken on relevant words, phrases or sentences mentioned in each of the interviews relevant to the research questions to create preliminary codes. Preliminary codes were created for each transcript/case study.
Generating initial themes	Preliminary codes were compared between them and grouped by commonalities relevant to the research questions. Once codes were grouped (mapping codes) they were examined to identify the most significant codes and compiled into potential themes.
Developing Themes: Reviewing and developing themes	Review of initial themes was done and re-examined to decide if they fit and were relevant to the research questions. Themes were given specific names and definitions were written for each of them. Four themes were initially obtained from this phase: <i>Milpa</i> Status; Farmer's priorities and challenges; Causes, impacts and adaptation strategies on climate change and knowledge associated with <i>milpa</i> .
Refining, defining and naming themes	Themes were re-defined and furthered grouped and name around three final and relevant themes: 1) Farmer's current perception/views of <i>milpa</i> (multiple perspectives); 2) Farmer's priorities and challenges when practicing <i>milpa</i> /agriculture and 3) Use and adaptation of knowledge in <i>milpa</i> system.
Writing	Based on these themes and by linking codes and subthemes three chapters related to findings were structured and written.

3.8.1.2 Surveys

Information collected from surveys was reviewed, organised, and entered into an Excel Database for coding and further analysis. Information was organised into six categories based on the content: a) Demographic; b) Acquisition and Transmission of Knowledge

in the *Milpa* System; c) Traditions and Knowledge in the *Milpa* System; d) Status of the *Milpa* System; and e) Climate Change and Impacts on the *Milpa* System. Once information was classified and codified and depending on the type of question, descriptive statistics, examination and plotting of frequencies were conducted using Excel and IBM SPSS Version 29.0. For open-ended questions content analysis was used to extract the most meaningful insights relevant to the research themes.

Results of qualitative analysis helped to identify differences and similarities between case studies and compared them with information obtained from community surveys. This also allowed the results of the quantitative analysis to be interpreted and to link all the information while considering both scientific data and farmer's worldviews and knowledge.

3.8.2 Quantitative Dataset

3.8.2.1 Soil samples

Eight composite soil samples from cultivated plots and six from non-cultivated areas (See 3.7.2.1.1.) were processed and analysed for the following physical and chemical properties.

a) Soil colour

Colour of soil is the property used to help determine the pedogenic processes in soils and is influenced by the soil's mineral composition, organic matter and water; which depending on the content can present a variety of colours (FAO 2006). Soil colour is an important property as it can reflect the temperature and moisture characteristics of a specific climate, but also can help to estimate soil fertility and their viability for agriculture (Łachacz and Załuski, 2023). An initial characterization of soil regarding colour was done together with the farmers and then compared with those obtained by the Munsell system. The Munsell system of colour notation (Munsell, 1994) for hue, value and chroma, was followed to identify the colour of the soil surface horizon in the moist condition for each of the eight composite samples (FAO 2006).

b) Particle Size distribution and Soil Texture.

Particle size will affect the physical properties of soils and can influence drainage, water holding and ease of cultivation (Rowell, 1994). Soil texture is a mixture of different particle-size classes in a soil volume (FAO, 1996). Soils can be allocated to textural classes each of them given a specific particle size distribution (sand, silt, clay; PSD; Rowell, 1994). Soil texture is a basic property of the soil which is often used to assess soil behaviour and can influence soil colour (Brady and Weil, 2008). Although around the world there are many national systems used to describe particle-size and soil texture (e.g United States Department of Agriculture-USDA) this study used a UK classification system developed by the Agricultural Development and Advisory Service (ADAS), and the former Soil Survey of England and Wales (now the Soil Survey and Land Research Centre/SSLRC).

A Laser Diffraction Method (LDM; Agrawal et al., 1991) was used to determine the size of the mineral particles present in each of the composite samples. A 2ml scope from each of the soil samples were processed in a tube, and organic matter was removed using a peroxide treatment (approximately 30ml). Once this was done all the samples were submerged in water at 80C for 3-4 hours to separate sediment from peroxide. All samples were centrifuged three times at 2000 rpm for five minutes to wash out the peroxide. After this is completed 10 ml of Calgon were added to each sample and shaken, left to rest and then taken to the laser analyser. Using a pipette, the soil sample was added slowly in deionized water and later passed through a flow cell in the path of a laser beam. Depending on the size of the particle a specific amount of light is diffracted. The diffraction pattern determined the size and number of particles within each sample.

A LS 13-320 Laser Diffraction Particle Size Analyser (Beckman Coulter) was used to help identify the particle size through a Polarization Intensity Differential Scattering technique (PIDS) as this method provides more distinctive signatures of particle size than conventional laser scattering. Through this technique scattered light from both vertically and horizontally polarized incident light of three wavelengths is measured. A pattern is formed by the differences between the two polarizations. Data from both the PIDS and laser scattering is combined allowing to determine the size and number of particles within each sample. After the particle size was determined soil texture classes were identified using the ADAS triangle structure (Figure 3.8).

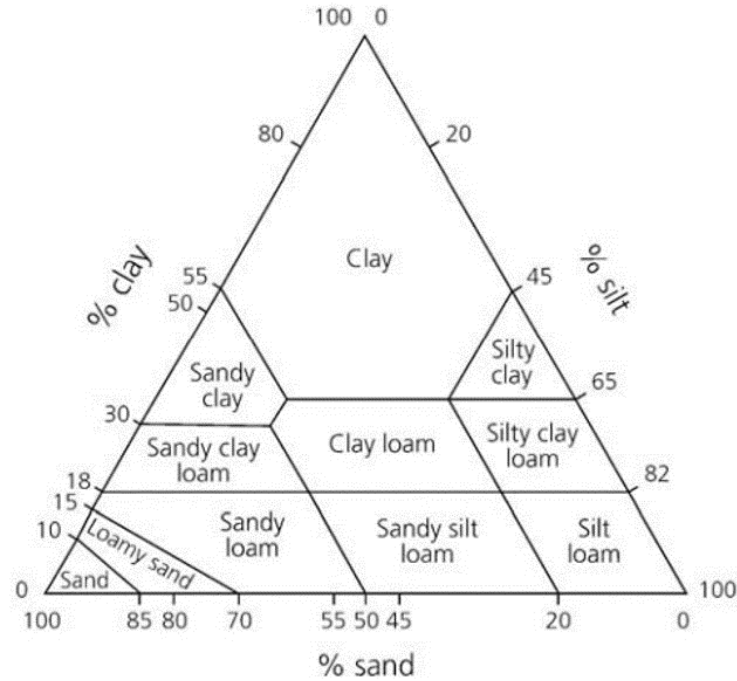


Figure 4.7. Triangle structure for the determination of Soil Textural class based on the UK classification.

Soil texture was compared with traditional descriptions provided by farmers. This process allowed a better understanding of the characteristics of different types of soils viewed from both a scientific and a traditional perspective in a region with specific micro topographical conditions and which have historically played a relevant role in the type of maize variety that can be cultivated. Similarly, this process allowed the impact of the different types of management within soils with different textural classes to be understood.

c) Organic matter content

In agricultural soil, organic matter (OM) is linked to fertility and productivity since it provides the soil with macro and micronutrients. A loss on ignition (LOI) process was used to determine weight percent of the organic content in soils from the studied plots. Estimation of soil organic matter was done by comparing the gravimetric weight change of each of the eight samples when exposed to high temperature oxidation. In doing so the samples were first subject to an initial oven drying at 105°C (water content), and then further ignited in a furnace at 550°C. Percentage of weight loss obtained was reported as OM % (% wt. loss; Ball, 1964; Heiri et al. 2001).

d) Soil Acidity (pH - colorimetric method).

Temperature, rainfall and geology can influence soil chemical and biological properties such as acidity and alkalinity (Rowel, 1994). In agricultural soils, pH is a major determinant of which crops can grow in each site. Soil pH is an important property since it can help to define which nutrients are available for plant uptake (FAO, 2020); however, management of soils can affect this property. This is important in a crop system like *milpa* where several crops are grown throughout the year and given that it is managed in many ways (Hernández Xolocotzi et al., 1995; S. Terán & Rasmussen, 1994). The pH colorimetric method involved using a chemical indicator that changes colour based on the acidity or alkalinity of the soil, which was visually compared to a colour chart to determine the pH value. From each sample, a fixed volume of soil (1ml scoop soil) and a small scoop of barium sulphate (white powder) were added into an empty test tube and mixed with distilled water in a ratio of 1:2 (soil: water) and shaken. After shaking, a pH indicator (bromothymol blue) was added to the soil suspension, shaken gently and allowed to stand for 10 minutes. The resulting colour was compared with a standard pH colour chart corresponding to a specific pH value ranging from acidic (around 4.0) to alkaline (above 8.0).

e) Macronutrient Availability (nitrate-nitrogen, potassium and phosphorus)

A standard colorimetric and photometric (Palintest SKW500) analysis was used to determine the macronutrient availability for each of the composite samples. Nitrate Nitrogen ($\text{NO}_3\text{-N}$), phosphorus/phosphate (P), and potassium (K) are the most important nutrients that contribute to plant growth and increased yield therefore they were analysed to gain useful data around soil fertility of the eight plots monitored under different management practices (Weil and Brady, 2016). The Palintest Soil Fertility Kit was used to test major nutrients by extracting the nutrients from the soil samples and then testing the extracts following simple test procedures. The analysis measured the nutrients or trace elements which are 'exchangeable' or 'extractable' under the conditions of the test. For nitrate and phosphate, the test used a colour comparison method, while the potassium used a procedure based on the amount of turbidity formed in the sample. For each of the nutrients tested the soil samples were prepared and mixed with an extracting solution in order to extract the nutrient or trace element from the soil and conduct the appropriate test. The extraction process was done following the Palintest Soil Fertility Kit Manual

(Table 4) which uses a photometric testing based on the optical absorption or scattering principles which measures the intensity of incident light compared to the light intensity reaching the detector array. The optical absorbance technique consists on creating visible colours (depending on the nutrient) with specific chemical reagents upon reaction following an extraction process. The intensity of colour produced by the sample tested is measured with a photometer and the data compared to calibration data. Optical scattering techniques produce small particles to scatter the source beam, the amount of scatter providing a result for the concentration of parameter under test (Palintest Manual, 2016). Results obtained in the analysis were expressed as mg/L or ppm.

Table 4.4. Description of characteristics and soil extraction procedures conducted for each of the composite samples in relation to Nitrate Nitrogen, Phosphorus and Potassium (Extracted from Palintest Soil Fertility Kit Manual, 2016)

Nitrate (0 – 25 mg/l N)	Nitrate nitrogen (NO ₃ -N) is an important plant nutrient which promotes foliar growth and increased yield. In the Palintest Nitrate test the soil is extracted using 1M ammonium chloride at a soil:water ratio of 1:25. The extracted nitrate is reduced to nitrite during the extraction stage and then reacted to form a red azodye. The intensity of the red colour produced is proportional to the nitrate level in the soil sample.
Phosphate (0 – 100 mg/l P)	Phosphate (P) is a major plant nutrient. It is particularly beneficial in stimulating root growth. In the Palintest Phosphate test the soil is extracted using 0.5M sodium bicarbonate at a soil:water ratio of 1:25. The extracted phosphate is then reacted with ammonium molybdate under reducing conditions in acidic solution to form a blue coloured complex. The intensity of the blue coloration is proportional to the phosphate level in the soil sample.
Potassium (0 – 280 mg/l K)	Potassium, the third of the major nutrients, increases resistance to disease and hardens plant tissue. In the Palintest Potassium (K) test the soil is extracted using 0.1M magnesium acetate at a soil:water ratio 1:25. The extracted potassium is reacted with sodium tetraphenylboron to form an insoluble white complex which produces a turbidity in the test sample. The degree of turbidity (cloudiness) is proportional to the potassium level in the soil and is measured using a special double tube assembly.

Results from the laboratory analysis were entered into the IBM SPSS Statistics 29.0 Software and analysed across eight plots using descriptive statistics. In addition to this, to assess if there were any significant differences between properties from six farms

managed under *milpa* system versus six forested/non-cultivated areas a t-test was conducted, and results were plotted.

Both scientific and farmer's knowledge descriptions of soil characteristics were compared for similarities and differences. Information from semi-structured interviews in relation to *milpa* management and farmer's use of knowledge was used to interpret the quantitative results.

Given that in most cases this was the first-time farmers had had a soil test performed in their plots this information was compiled, shared and explained in two community workshops (See 3.8.3) for farmers to be familiar with the basic soil properties and their role in yield productivity. This also allowed dissemination of the benefits and challenges for soil health when practicing different management strategies and provided a better understanding for farmers on the impact of fertilizers, pesticides and climate variability on soil functionality.

3.8.2.2 Meteorological Data

Annual and monthly precipitation and temperature data for the period of 1991-2021 was reviewed from the selected stations to make sure they met the criteria to be included in the analysis. Not all stations were able to provide data for the specific 30-year period and therefore not included in certain analyses. Three important factors were analysed: Changes in precipitation and temperature across time for each of the three stations, precipitation and temperature anomalies and precipitation trends. Results of this analysis were then compared with the information provided by farmers around climate change and variability to look for similarities and differences (Berg, 2004).

Changes in weather conditions across time

Climatologies were used to summarize and describe the precipitation and temperature variability in the three studied communities over the 1991-2021 period. Descriptive statistics of average annual precipitation and average temperature were used to summarize and describe any significant changes across time. Differences in monthly average precipitation between the periods 1991-2001, 2002-2011 and 2012-2021 were examined to assess significant changes across seasons and decades for each of the three stations in addition to the 30-year period (1991-2021). A t-test for paired samples was conducted to see if changes were statistically significant between the period 1991-2021

and 2021 for each of the three stations. A one-factor analysis of variance (ANOVA) was used to examine if there were significant differences between the monthly average precipitation between the three stations across years and then across three different decades (1991-2001, 2002-2011, 2012-2021). A two-tailed t-test for independent samples (equal variances not assumed) was performed to analyse significance differences for mean annual temperature data from 1991-2021 for two stations (Peto and Central Farm) since no data was available for the third station (Libertad).

Precipitation and Temperature Anomalies

Examining long time series of precipitation variability can help to detect the potential changes in climate within a specific geographical area. This is particularly important in tropical areas such as the Yucatan Peninsula given that crops are highly dependent on rainfall, but also given the high sensitivity to annual rainfall amount that determines each of the life stages of *milpa*. A decrease or increase of precipitation with respect to the normal (average) quantity of precipitation in each climatic zone (anomalies) can be very important for crop production (Mardero et al., 2018) and for this study they helped to understand the most notable changes that have occurred within the study areas over the past 30 years.

Anomalies were calculated as the difference in precipitation or temperature observed in a specific period “i”, (P_i) with respect to the average (P) using the following formula $Anomaly = (P_i - P)$. Annual precipitation anomalies between 1991 and 2021 were calculated for three stations (Peto, Libertad and Central Farm). In the case of temperature annual anomalies for average temperature (T_{avg}), maximum (T_{max}) and minimum temperature (T_{min}) were calculated only for two stations (Peto, Yucatan and Central Farm, Western Belize) based on data availability (Mardero et al., 2018).

Annual Precipitation Trends

A trend is defined as the general movement of a series or the long-term change in a dependent variable over a specific period (Webber and Hawkins, 1980). A trend is expressed as the relationship between the variable of rainfall (or temperature) and their temporal resolution. Simple linear regression and coefficient of determination R^2 was used to assess the significance of trend for mean annual precipitation in three stations (Peto, Central Farm and Libertad). A one-factor analysis of variance (ANOVA) was used

to examine if changes were significant different (Mardero et al., 2018; Mardero et al., 2012; Panda and Sahu, 2019).

3.8.3 Community workshops and Knowledge Exchange

Once the fieldwork was finalised and results were analysed and given that Covid-19 restrictions were eased, two community workshops were conducted in each country in January 2023. The purpose of the workshops were a) to inform research participants of the outcomes of the research; b) promote knowledge exchange between farmers in relation to climate change impacts and adaptation strategies which allowed for triangulation of results obtained through surveys and interviews and c) distribute materials co-created as part of the benefit sharing principle (e.g. calendars, memory card game, infographics printed maps and soil results).

The structure of the workshops varied between Yucatan Mexico and Belize due to availability and time framework. The first workshop was held in Belize where farmers from San Antonio, San Jose Succotz and Patchakan, with support from the Ministry of Agriculture (MoA), travel to the Central Farm Government Facilities in Cayo District to meet each other in a learning exchange. This activity involved meeting with representatives from the extension services and with teachers from the University of Belize (UB) to exchange and assess experiences around climate change impacts and adaptation strategies. The workshop also included a presentation of the outcomes of the research, a quick session on soil health in order to share the results of the soil analysis and distribution of educational material.

In the case of Mexico, farmers from Xoy and Tzucacab travel to Maxcanu to meet farmers from that community. The workshop involved the same activities as in Belize (see above) but no government or academic institutions took part upon request from farmers. The workshop also included an exchange visit to different *milpas* outside of Maxcanu town centre in Oxkintok which promoted knowledge exchange as farmers were able to experience at first hand and through direct and participant observation, the challenges experienced, and management strategies put in place by other farmers. In doing this, the Maya Yucatec collective tradition of exchanging native seeds was also completed, followed by the traditional sharing of a *milpa* meal (any traditional dish made with crops obtained from the *milpa*), where ideas were exchanged resulting in a farmer to farmer learning experience. This allowed the researcher also to experience at first-

hand the ethos of Maya Yucatec people and epistemology of indigenous knowledge. Although exchange of native seeds is not that common in Belize and only in some cases between members of the same family, Maya Yucatec farmers in that country who took part in this event did share a *milpa* meal with the researcher at different times through the completion of fieldwork stating it as an important Maya tradition.

At the end of the workshop farmers were invited to provide anonymous feedback about the workshops which was used as part of the discussion and reflections on Chapter 7 (See Section 7.5.2)

3.9 Limitations of the study and statement of the impact of Covid-19 and extreme weather events in data collection.

Although every effort was made to minimize the impacts of external factors on the research, two main factors played a crucial role in how the study was carried out and adapted, thus impacting the information available to support and bridge the gap within the research questions. The first and major impact was the coronavirus disease (Covid-19) which impacted worldwide research and thus the original data plan collection. Although challenging, this also provided an opportunity for self-reflection on how knowledge systems (including scientific knowledge) adapt, particularly in disrupting times.

3.9.1 Interviews and surveys

At the time of most of the research restrictions from Covid-19 were in place across the study areas that limited interaction with a larger number of farmers for surveying purposes, thus limiting the number of surveys and interviews conducted within the planned fieldwork time. As a result, the original sample size proposed was reduced (See 3.7.1.2) to guarantee farmers safety especially given that some of the indigenous territories visited were in semi-remote areas and fieldwork visits were restricted to a small number of days. The research was forced to reduce the number of participants recruited to guarantee minimal exposure and risk to the participants given the conditions present at the time of the study.

As a result of this, the sample per community is not fully representative in all the six studied Maya Yucatec communities within Mexico and Belize, however it provides reliable information in relation to members of the same cultural group and sets the basis

for future research in the area particularly for Mexico, since the research conditions were more flexible and accessible.

In addition to this, as part of the principle of inclusion and benefit-sharing within the community and given the challenges to travel associated to Covid-19, a call for applications to hire and recruit community fieldwork assistants was done within three communities in Mexico. As a result, three young people were trained in different research skills and provided with a weekly stipend to assist with fieldwork activities when needed.

3.9.2 Meteorological records

The second major challenge was natural phenomena, which also illustrated the daily struggles of the inhabitants of the studied communities impacted by climate change. Efforts to monitor and collect data were maximised and was intended to monitor more than one agricultural season across years throughout the research, unfortunately this was not possible due to Covid-19 restrictions on travel and accessing local communities. This also prevented meteorological stations from being monitored frequently. During the development of the research two meteorological stations were placed in key areas, where national meteorological services have limited information, to help understand microclimate changes (See 3.7.2.1.2). In 2021, prior to visiting the study area Tropical Storms Cristobal and then Category 1 hurricane Gemma and Category 4 hurricane Delta in the Yucatan Peninsula damaged both stations resulting in considerable harm to the console leading to data loss. In September 2021 attempts to repair the stations were made. In 2022 the station in Maxcanu community was stolen because of urban development being carried out as part of the construction of the Tren Maya (Maya Train) leading also to data loss. Later that same year impacts of Hurricane Ian damaged the remaining console in Hobonil (Tzucacab). In 2023 the station was re visited and some data were collected however data cleaning showed that the station console was damaged, making the available data unreliable for the purpose of the research. This led to abandoning use of data from those meteorological stations and relying solely on information provided by the National Meteorological systems in Yucatan, Mexico and Belize.

Results from the data collection described above are presented within the next three chapters (4,5,6) and merged and integrated, analysis of both qualitative and quantitative datasets were guided by both indigenous and scientific knowledge.

CHAPTER 4 The Maya *Milpa* in Mexico and Belize: A multiple-perspective reflection on agriculture and knowledge systems.

4.1 Introduction

Milpa has been present in Mexico for about 7,000 years and in the Yucatan Peninsula for about 4,000 years (Chapter 2, Section 2.6.2; Terán et al., 1998) and has been adapted and transformed throughout time due to different environmental and socioeconomic elements (Harvey et al., 2018; Mardero et al., 2018; Schmook et al., 2013). As a result of this transformation, *milpa* practitioners have also shifted their notion of the *milpa* system.

In contemporary *milpa* systems multiple factors can play a role in the way farmers perceive *milpa* and consequently in the way they manage and adapt the system, and how they use scientific and indigenous knowledge in daily life and in the face of challenges. This chapter examines how *milpa* is currently viewed by farmers from Mexico and Belize and which environmental, socioeconomic, cultural and political factors play a role and are prioritised in the system. In doing this, the worldviews of Yucatan Peninsula Maya farmers and the different forms and aspects of indigenous knowledge are explored. Particular attention is paid to the innate relationship Maya farmers have with nature, specifically with the *monte* (primary or secondary forest) and how changes in the dynamic of this relationship can be a major factor influencing the notion of practicing *milpa* in modern Maya communities and in adapting to challenges such as climate change. In exploring the use and adaptation of knowledge, the implications of modern globalised science on indigenous knowledge and its role in local cultural adaptation is also examined.

4.1 Nature and culture: Historical and current relationship among the Mayan milperos of Mexico and Belize with the *Monte*

Although there have been many discussions and studies about the reasons why the *milpa* has survived across time, despite the potential influence of external factors either economic or political, the reality is that the survival of Mayan agriculture is in part still tied to the collective memory and identity of the ancient Mayas and their historical relationship with nature and gods (Bracamonte, 2001; Tuz-Chi, 2010); but also to the continuous social networks that have surrounded this system. Maya cosmogony has been characterized as describing processes of creation and destruction and is embedded in

books, codices and poems like the Chilam Balam, the Rabinal Achi and the Cantares de Dzitbalche (Tuz-Chi, 2010).

One of the worldviews that has survived across time has to do with the *monte* (Garcia-Quintanilla, 2015). *Monte* which in Maya language is *k'áax* is seen by Maya milperos as a supernatural being and as a living entity rather than just a place (Terán et al., 1998). According to Terán et al. (1998) Terán et al. (1998), there is a strong connection between Maya milperos and the *monte*, in which farmers are fully aware that *monte* is not their property and it is their responsibility to take care of it, to give thanks to superior forces that inhabit it and to give back what is provided in order to maintain a balance translated into good yields.

The connection with the *monte* is a Maya worldview well documented through pre-colonial and post-colonial references (Garcia-Quintanilla, 2000; Landa, 1566; Recinos, 1960; Terán et al., 1998; Thompson, 1979; Tuz, 2009). Literature like the Popol Vuh (Recinos, 1960) and Relatos de Yucatan (Landa, 1566) have described the worldview of the Maya peninsular people around the *monte*. In the Popol Vuh, considered the Mayan sacred book, the creation of the mountains, valleys, animals, plants that are part of the *monte* and humans is described, together with the elements shaped to protect all that has been created like the guardians of the *monte* called *Yuumtsilo'ob*, the lords of the *monte* called *Yuum K'áaxo'ob* and the guardians of the *milpa* called *Aluxes*. Elements like hurricanes, destructive rain and pests that are sent to punish humans who do not worship the sacred gods that inhabit the *monte*, and all that exists in it, are also described (Garcia-Quintanilla, 2000; Recinos, 1960; Tuz, 2009). Additional elements like the sun, the stars, and the moon are also mentioned as part of this relationship, some of which are associated with modern Mayan worldviews around agriculture. In Landa's description of daily life in Yucatan around 1562 (See Chapter 3, Section 3.5) different portrayals of Mayan worldviews through ceremonies performed by Maya peoples to the gods are described, one of them for the protection of the maize fields from birds and ants and to have good harvest (Landa, 1566).

With the Spanish colonization of Yucatan in 1517 these worldviews and associated practices were impacted by the imposition of a religion and political ideologies which considered Maya peoples' worldviews as idolatrous, severely punishing those who practiced them (Bracamonte and Solis, 1996; Sanchez de Aguilar, 1613; Tuz, 2009).

However, according to Bracamonte and Solis (1996) the ancestral knowledge associated with Maya worldviews, particularly those associated with the *monte* and agriculture, survived colonial dynamics across time in the collective roots of the Mayan people through oral tradition, religious expressions and rituals. The survival of these worldviews, however, went through an “involuntary” knowledge system adaptation given that many of the holders of the ancestral knowledge adopted many of the Christian rituals and merged them as a single religious knowledge system where pre-Hispanic worldviews and evangelised views were combined, resulting in modern forms of indigenous knowledge (Tuz-Chi, 2010).

Distinctive cultural features and worldviews of Maya Yucatec milperos in Mexico and Belize have remained across both countries, however micro differentiations influenced by multiple factors have continued to impact the dynamic of the relationship with the *monte* (Tuz-Chi, 2010). As a result, indigenous knowledge systems associated to these known worldviews have been modified and have continued to adapt to current societal demands, but reduced to mystical activities (Terán et al., 1998).

The following are indigenous knowledge portrayals associated with different stages of “making *milpa*” mentioned and used by participants in the case study analysis. A description was provided by farmers (Table 4.1) and reviewed with the use of the published literature. These elements played an important role in understanding the position and relevance of worldviews in adaptation responses further in the research.

Table 5.1. Indigenous knowledge portrayals reported by Maya farmers in Mexico and Belize

Name	Description	Type of knowledge
XOOK K'ÍIN-CABANUELAS (ANNUAL WEATHER FORECAST)	Annual weather prediction system that is conducted during January and consists on observing and recording the meteorological conditions throughout the month in order to plan annual agricultural activities (e.g. slash and burn, planting, etc) and agricultural rituals and ceremonies (Cat, 2015)	Belief
CHA' CHA'AK (RAIN PETITION CEREMONY)	Ritual performed in honour of the God Chac (the god of rain). It used to be performed between March and May but currently is performed around the beginning of the traditional annual rainy season (May or June). The main purpose of the	Ritual

	ritual is to ensure rain falls on time in order to achieve a successful yield (Russell, 2016).	
SA'KAAB	Ceremony to offer a maize-based beverage called Sa'kab to feed the gods (<i>yuumtsilo'ob</i>) that live in and protect the <i>monte</i> . This ceremony is offered to ask permission to enter the <i>monte</i> and for the guardians of the <i>monte</i> to protect farmers, their families and their animals from evil when working the land that was lent to them. Is offered from April to July (Cat, 2015).	Ritual
WUAJI KOOL OR U JANLI KOOL	The translation of this ceremony is “food of the <i>milpa</i> ” and is a way of showing reciprocity to the gods and maintaining the order within the cosmos. The ceremony is considered a “major event” so it can only be performed by a maya priest (h'men or jmeen) given the complexity of the ceremony. It is both a ceremony to ask permission to the lords of the <i>monte</i> to work the land and a thanksgiving ceremony to the lords of the <i>monte</i> for the blessings received throughout the year and that made possible to have the harvest. The ceremony is conducted before the planting season.(Cahuich Campos et al., 2014)	Ritual
JO'OLCHE' OR JO'OLBESAJ KOOL (PRIMICIA)	Ritual performed normally in September (but also October and even November depending on when farmers sow) to express gratitude for the first harvest. The ritual consists on selecting the first and best crops harvested and prepare a special meal made from tender corn and offered to the god of the rain, the god of the <i>monte</i> and all the guardians of the <i>milpa</i> for the crops produced (Red Mayense de Guardianes y Guardianas de las Semillas, 2023).	Ritual
OOL	The essence of being, defined as the whole; it is the spirit, the soul and energy of man and nature. It is the “holy grace” without the ool, man would not live (Tuz-Chi, 2010)	Belief
TZOLK'IN (MOON PHASES)	The different phases of the moon are used to conduct the different activities in the <i>milpa</i> (clean the plot, sowing, harvesting, etc). Every phase has a specific purpose and if not performed in the right phase it leads to poor yields.	Belief

KANICULA	Meteorological phenomenon (temporary disruption of summer rainy season) that begins during the warmest time of the year (around the summer solstice or later). It's a stage when farmers skills and cultures are challenged as it defines the success or failure of <i>milpas</i> . Rain and drought of the following days are forecast by observing behaviour of this phenomenon (Cat, 2015).	Belief
BIOINDICATORS	Behaviours of animals, plants and even natural phenomena like the sun and the moon are observed to predict local meteorological conditions. They are used year-round to predict the weather conditions that would come in the next hours and days. They are used round year and help to make decisions regarding <i>milpa</i> management (Red Mayense de Guardianes y Guardianas de las Semillas, 2023).	Belief

4.1.1. Differences and similarities in worldviews around *milpa* and *monte*

In this research, an indicator on how deep and present is the current relationship between Maya milperos, and the *monte* was observed in the different ways of naming *milpa*. Although *milpa* is the most common name used to refer to this agro-system throughout Mesoamerica, among the Mayan people this term varies between Mayan groups. The Maya Yucatec people, use the Maya name *kool* or *ix kool*. Garcia-Quintanilla's (2000) work emphasizes that the use of the word *kol*, which in historical records has been used as "taking away", is a reminder to milperos that making *milpa* is "taking away from the *monte*", and in order to keep the balance between the *monte* and humans, the milperos should continue to make offerings, ask permission and forgiveness for taking away to what belongs to the *monte*. Dehouve (2008, p.4) explains this by describing that *milpa* "represents a way of extracting resources from nature that rests on a broad social, symbolic and ritual construction".

Maya farmers in the Yucatan state in Mexico and in Belize reported different ways of naming *milpa*, resulting in ten different terms. The most common term used besides *milpa* was "*parcela*" (plot) a term popular used among outsiders (e.g. agronomists) followed by ranch and the maya term *ix' kool* or *kool*. There were however differences between Maya farmers in Yucatan and those in Belize. In Yucatan the most common name used was *milpa*, *parcela* or *ix' kool* and *kool*, whereas in Belize it was *milpa*, farm

or ranch. Other names mentioned included land (*terreno*), estate (*finca*) and vegetable garden (*huerto*). Farmers who took part in this research as case studies, in both Mexico and Belize, were inclined to use the term *parcela* or *milpa* interchangeably.

Farmers who took part in this research (for methods see Chapter 3) reported that independently of the name used, *milpa* is defined as an activity for producing food (self-subsistence-oriented system). However, in Mexico farmers mentioned that *milpa* also involves a strong cultural relationship with the *monte* and with many environmental and religious elements. In Belize, this relationship with the *monte* was less frequently expressed compared to farmers in Mexico (given that in their words “traditional” *milpa* involves cutting down the forest and clearing the land, an activity that is no longer practiced given the Belizean environmental regulations that forbid this practice), but not necessarily absent only expressed differently. In Mexico, *milpa* was seen by farmers as a reciprocal relationship with the *monte*, however in Belize this relationship was not clearly stated during interviews and surveys but was mentioned during participant observation by referring to “things done to nature (like using poison/chemicals) and getting consequences in return for not taking care of it”.

The research found that for farmers with a worldview around nature/*monte*, “making *milpa*” is not only an activity related to the production of food, but a relationship of reciprocity with nature and specifically with the *monte* that must be built and taken care of by carrying out different meaningful ceremonies that help to keep this relationship balanced (Garcia-Quintanilla, 2000; Tuz-Chi, 2010). In doing so, the transmission of the language is important to be able to carry out this knowledge, failing to do so resulting in the loss of their cultural identity and loss of the *milpa* system, a concern expressed by farmers in Xoy and Oxkintok in Yucatan and in Patchakan, Belize (Chapter 3).

“I am a bit worried and sad. Sad that the values of the grandparents are being lost and if we continue like this, we will no longer have that culture to demonstrate to the new generations.”

Farm 2, Oxkintok, Belize 2021

“It's sad because all things, customs or beliefs are something that can be forgotten, and culture can be lost. For us as Mayas or as people from here in Yucatan, it is sad because the time will come when they will no longer give importance to it. We are the last ones in this time, and the time will come when young people like those who are growing now if they don't follow up if they don't have those beliefs the time will come when everything will be forgotten, it will be forgotten and our culture and customs will be lost.”

Farm 4, Xoy, Mexico 2021

“The truth is that it feels sad honestly. Speaking of this, let me bring into the conversation the topic about the language. My dad is Mayero (Maya person), he speaks Maya and everything, but nevertheless I can't make a conversation in Maya. I can't understand many things because my dad didn't pass me his language, so now it's Spanish and English. And just as I see it, with this language thing, this is happening also with the milpa and all that [the traditions]. Truth is, that it would be an excellent idea to preserve and rescue our tradition because it is part of us, that is what identifies us, one could say those people are Mayeros, they are Yucatecans by their way of speaking, by their system, even by their clothing.”

Farm 8, Patchakan, Belize 2021

Symbolism in traditions, rituals, practices and beliefs in the *milpa* were expressed differently in both countries as a result of different ways of viewing the world and *milpa*. According to Santos-Fita et al. (2013, p. 90) the differentiation of farmers' visions of the *milpa* is explained by their symbolic practices, suggesting that *milpa* “reveal their beliefs and ritual practices —individual or collective— and, by extension, their schemes of representation and vision of the world or worldview”.

Changes in the local environment from where these views originated have brought a change in views of the *monte* and consequently the relationship with it has also been modified. However, the fact that in both countries, a strong connection with post-colonial religious rituals to ask for good yields and protection of the land and work was documented during surveys, interviews and participant observation indicates that cultural views/worldviews are still used but are expressed differently, and although not recognised, they are a form of adapted indigenous knowledge.

In the case of Mexico, cultural views and knowledge associated with these views were found to be embedded into ancestral practices related with the *monte* (eg. Sakaab and Primicias, see Table 1) and Christian/catholic practices where God (Jesus) is also adored and included as an essential part of the rituals offered to the *monte*. In Belize, however, cultural views and knowledge associated with those views were documented around

prayers to God (Jesus) considered essential for *milpa* and agriculture to provide good yields and during challenging times, but not associated with any rituals of nature.

This belief between nature and God was explained by Tuz-Chi (2010, p. 113) “For the Maya peninsular people God is a communion between the Catholic and the pre-Hispanic, which generates an open mind and soul. Nature is their main ally, because what it is recognized as a living being and as part of God, nature is the gift of True God and under that syncretic perception it is necessary to worship him. God in the current Mayan worldview, is an omnipotent being, is the creator of all things. God is the Supreme Being and he has servants who they help take care of every corner of the earth”.

Although different visions of the *milpa* can be observed, *milpas* were found to still be managed following an ethos of care and an interconnected relationship between either the *monte* (or some elements of it) or a superior being (God) and the milperos, but expressed differently and not at the same level between countries. The relevance of an ethos of care with nature has been documented in other indigenous groups across the world as a major element influencing individuals and societies behaviour (Kealiikanakaoleohaililani & Giardina, 2016; McGregor, 2004; Salmond, 2014; K. P. Whyte et al., 2016; Wildcat, 2013; Ziker et al., 2016). This reciprocal relation is considered the epistemology of indigenous knowledge, but often misinterpreted as mystical (Bang et al., 2018) and hence dismissed by modern globalised knowledge. In the case of the *milpa* worldviews and religious practices are “logical explanations derived from the rationality of the *milpa* production system” (Terán et al., 1998, p. 35).

The results from this research found that modern *milpa* is seen by Maya Yucatec farmers beyond the concept of a biocultural agri-food system as a unique form of dynamic indigenous knowledge that continues to be based on the historical tradition of observing nature (Berkes et al., 2000). *Milpa* is seen not only as part of farmer’s individual and collective lives, but as a cultural conception of place and territory, and its management as a cultural act, a value and a responsibility embedded in values, rituals, visions and knowledges expressed differently even within the same cultural group (Muller et al., 2019; Nursey-Bray et al., 2020).

4.2 Current status of the Maya *milpa* in Mexico and Belize

4.2.1 Perception and structure of *milpa*.

One of the most evident characteristics observed between contemporary Maya Yucatec *milpas* in Mexico and Belize was found in the ways *milpa* is currently defined by farmers. Responses from the survey in relation to *milpa* description were displayed in a word cloud (Figure 4.1) and showed that overall, in both countries *milpa* is frequently associated with “a place to plant beans, maize and squash” and “to get food and income for the family”.



Figure 5.1. Frequent words associated with the description of a *milpa* in Mexico and Belize.

Descriptions given by participants in the case study analysis in Mexico and Belize supported this conceptualization.

"Well, for us here in Yucatán the main thing is to have maize, maize and associates, which would be beans, ibes (local white beans), squash, pumpkin, sweet potato, yucca, everything that can be planted in the milpa, for us that is what having a milpa means. It is to have everything that can be produced and consumed, everything that can be consumed in the house, because from the milpa comes everything that is consumed both for us and for our animals that we have..."

Farmer 4, Xoy, Mexico, 2021

“Well, when we plant the milpa, we plant the maize that is our food...Tortilla, that's where the tortilla comes from. Yucca is planted in the milpa. Food like squash, beans, from the milpa we get everything for our own good. ...Milpa, let's say it's a place where we clean to sow crops”

Farmer 5, San Antonio, Belize, 2021

However, when analysing the conceptualization of *milpa* by farmers in Mexico and Belize separately, it was shown that Maya farmers in Belize define *milpa* as “a place to plant maize and beans but also many different crops” mostly vegetables such as squash, cabbage, melon, tomatoes, axiote, yucca, peanuts, onions, carrots, radishes, courgettes, lettuce, cucumber, sweet peppers, okra, and fruit trees (Figure 4.2). While in Mexico Maya farmers associated *milpa* mostly with maize, beans and squash, but also with social and economic elements such as family, food and income (Figure 4.3).

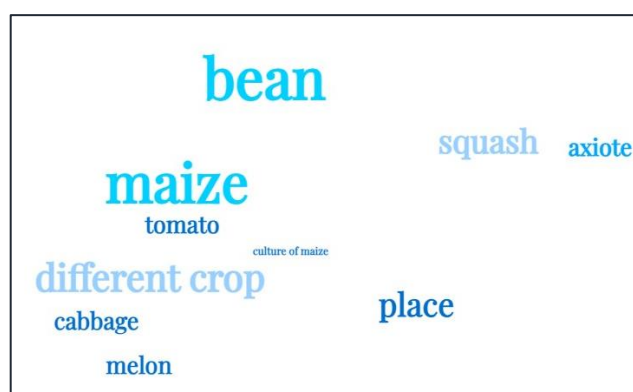


Figure 5.2. Frequent words associated with the description of a *milpa* reported by Maya Yucatec farmers in Belize.

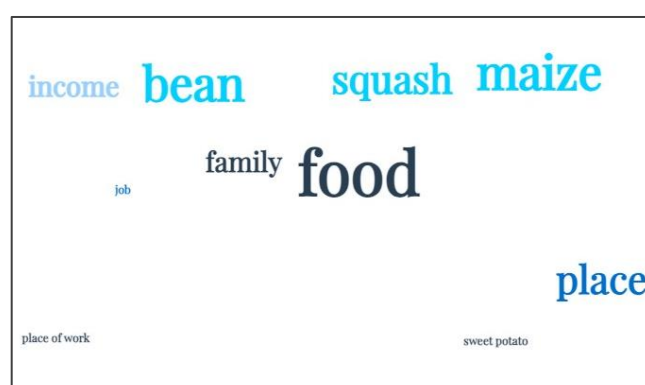


Figure 5.3. Frequent words associated with the description of a *milpa* reported by Maya Yucatec farmers in Mexico.

Differences between these systems were also identified based on how *milpa* is structured and managed. These differences in structure in *milpas* from Mexico and Belize were clearly seen during participant observation and allowed farmer's priorities in relation to this system, particularly in terms of management, to be identified and assigned. But it was also possible to describe the current use of rituals and practices associated with the *milpa* and their attachment to the *monte*.

According to Terán (2010), the Maya *milpa* is organized in three levels of existence: as a technical system, as a productive system and as a socio-cultural system (Table 4.2).

Table 5.2. Levels of existence in the *milpa* adapted from Terán (2010).

Level	Type of system	Characteristics
First Level	Technical	Involves all the technical resources, plant genetics, cultivated land, knowledge and rituals.
Second Level	Productive	Involves a set of productive activities including hunting, beekeeping, livestock, solar ranching agriculture (plot used for a number of domestic activities including growing crops, raising backyard animals), small-scale commercialization, handcrafts production, paid work and labour migration that are organized and carried out around the needs of la <i>milpa</i> and are integrated as part of the local economy.
Third Level	Socio-Cultural	Encompasses culture as an organising element of the family, the community, political organization, worldview, knowledge, values, ritual manifestations and practices and customs associated with food. It can have its own dynamics, but it should always ensure that the productive system works and reproduces.

4.2.1.1 Perception of *milpa* and Farmer's Priorities

Terán (2010) classification was used in the research to sort the way farmers prioritize *milpa* as a system in each country which highlighted key similarities and differences. On identifying the level of existence that farmers prioritize, it was also possible to understand how and why *milpas* are managed a certain way and how knowledge is used and adapted.

Descriptions provided by farmers in Belize had a stronger inclination to prioritize Terán's first level of existence (Table 4.2), meaning that *milpa* is seen predominantly as a technical system. *Milpas* monitored in Belize were found to be widely heterogeneous plots where maize is present, although not as the main crop. Instead, plots were commonly

composed of a great variety of vegetables and fruit trees (crop diversification) and in some cases dominated by fruit trees with only a small portion of maize.

In Mexico, *milpas* were for the most part homogenous areas planted with different maize varieties (at different stages depending on the variety), together with squash and beans planted in between. In some cases, other crops are planted such as sweet potato, or watermelon. This is what mainly differentiated *milpas* in Belize (Figure 4.4a) from those in Mexico (Figure 4.4b).



Figure 5.4. Overview of two different *milpas* in Belize (a) and Mexico (b).

When recording each of the management practices, crop diversification was found to be common. Crop diversification has been documented as an adaptive mechanism (Altieri

et al., 2015) and as a strategy for minimizing risks (Thrupp, 1998), thus indicating that management practices are implemented to fulfil this purpose.

In Belize, three of the four case studies (Farm 5, Farm 6 and Farm 8) shared the structure described above (crop diversification with a high predominance of vegetables) within their plot, and this was a common structure observed in surrounding plots within the studied communities. In this type of structure, farmers not only prioritize their plot as a technical and productive system, but in doing this they give high importance to technical resources and crops that can provide access to better marketing opportunities. In this kind of system, practicing traditional *milpa* as in the past, is no longer done since isn't productive anymore and thus the system has changed; now *milpa* management is guided by market needs and prioritising knowledge that can ensure more production with less effort and low cost (Vázquez González et al., 2018a). Although maize is cultivated (using both local and hybrid varieties) this crop is no longer a priority and has remained in the system because of their dependency on it as part of their daily diet.

One of the four case studies in Belize (Farm 7-HY) featured a plot cultivated with maize as a monocrop and where crop diversification is no longer used. This was an example of a plot structured with a tendency towards prioritizing *milpa* as a productive system according to Teran's (2010) description (Table 4.2). In this case, the main reason for this structure was to have maize constantly harvested for the farmer to be able to sell it year round, rather than only during a specific season and to be able to have maize available for his own use, without any restriction, since it is still a major component of the family's diet. The structure of this plot consists of planting a portion of the plot every month using a short-term hybrid variety (2.5 months growing period). In this way the plot is productive all year round in terms of income, paid work and food security. It also allows the farmer to focus on other productive activities such as livestock away from the *milpa*. Although it would have been expected that with this system the technical resources and use of more technical knowledge would also be a priority, the farmer continues to do *milpa* in the traditional way with many socio-cultural elements being prioritized such as the use of moon phases to plant and harvest. Despite the evident transformation of a *milpa* into a monocrop, the farmer still considers and continues calling his system a *milpa*. In this case the farmer sees *milpa* as a cultural conception of place and a bearer of history, family heritage and knowledge adapted for marketing purposes.

In the research sites in Mexico, it was observed that *milpas* are still mainly cultivated with different varieties of maize as the main crop with a high preference for native varieties over hybrids. There are other associated crops planted including beans, squash, yucca, watermelon, habanero chili, but in smaller quantities compared to maize and which are also used for self-subsistence. Some of these crops are sold in the community, but in small quantities and marketing is not a priority but instead cultivation is to protect native seeds, traditions and cultural identity.

Considering Teran's levels of existence (2010), *milpas* in the studied plots in Mexico had a predominant structure that prioritizes the third level of existence where *milpa* is highly perceived as a social-cultural system (Table 4.2), that then integrates the first and second levels of existence (technical and productive). Given the influence of social and government programmes, but also of climate change impacts, this structure is rapidly transforming and moving towards prioritising the first level of existence as the sole motive, potentially leaving out traditional ways of life that have persisted across generations. Results showed above indicated that in both countries *milpa* has changed and has been transformed from what it used to be, but the development model has occurred differently and shaped by different factors.

Vazquez-Gonzalez et al. (2018) reported similar transformation processes in two different communities in Yucatan Mexico (Xohuayan and Kampocolche) which portrays the two different types of transformation in the studied Maya Yucatec communities from Belize and Mexico. The first type of transformation and which was predominant in Maya Yucatec farms in Belize, is characterized by more evolved agri-food systems and where transformations occur both in the agricultural system and in the agricultural calendars to adapt to market demands. Here "based on productive strategies, Mayan farmers transform their available capital into products with use value and exchange value...and based on those incorporated into different types of marketing" (Vazquez-Gonzalez et al., 2018, p. 15). As a result, more open, diverse and flexible agricultural systems can be seen, but as argued by the authors they are highly dependent on external inputs such as hybrid seeds, chemicals, water irrigation to achieve productivity and are highly influenced by modernization discourses. Farmers in this type of transformed system haven't fully abandoned their social processes, nor certain cultural dynamics, but instead they have adopted "modern rationalities based on their own cultural identity and where changes have occurred towards and increased productivity" (Vazquez Gonzalez, et al.,

2018, p. 15). This could also explain why agri-food systems in Belize prefer all different types of crops that can be marketed and why there is a tendency towards prioritizing modern globalized science over indigenous knowledge and using only indigenous knowledge that can contribute to productivity (e.g. moon phases).

The second transformation approach reported by Vazquez-Gonzalez et al. (2018) in Kampocolche Yucatan, aligns to the transformation model reported in the three Maya Yucatec communities in Yucatan, Mexico. Here, Maya farmers have kept their traditional systems and where livelihoods are “attached to the Mayan tradition, and they avoid political control and modernization based on their autonomous cultural elements” Vazquez-Gonzalez et al. (2018, p. 16). These systems are mostly self-reproducing and self-sufficient and dependant on local inputs like native seeds and traditional tools and indigenous knowledge. The authors argued that systems like this have also gone through a type of development, however the transformation follows a “mechanism of resistance to the hegemonic market system, since it regulates social principles within the community such as reciprocity, as opposed to capitalist accumulation” (p. 15) to respect Maya Yucatec people self-determination. As a result, priority is given to social and cultural dynamics such as worldviews and self-knowledges (e.g. indigenous knowledge). De Sousa Santos (2016, p. 199) contributes to this argument by highlighting that forms of self-knowledge are prioritised “to organize resistance against the unequal relations caused by capitalism and colonialism”. These elements were frequently observed and identified in many of the narratives of Maya Yucatec farmers in Mexico and where indigenous knowledge played a crucial role.

4.2.2. The use of indigenous knowledge systems

The presence and use of indigenous knowledge systems among Maya Yucatec farmers offered an important insight into the current status of *milpa*, but similarly into changes that have occurred within this system (Bracamonte, 2001). Participant observation and results from the interviews and surveys indicated that rituals, beliefs, worldviews and symbolism continue to be relevant in the life of Maya farmers and are part of indigenous epistemology on relationality (Bang et al., 2018).

Santos-Fita et al. (2015, p. 2) argue that for the Maya people of the Yucatan peninsula “Rituals are rooted in the profound belief that human beings cannot live without making associations between their destiny and the natural and supernatural elements of nature.

For the Maya gods, spirits, and other forms of hidden and mysterious forces remain”, meaning that a reciprocal relationship is needed to maintain the balance in the world (Santos-Fita et al., 2015).

A first approach in understanding the current status of the relationship between farmers and *monte* was documented through the experience of farmers around the use of indigenous knowledge through rituals in *milpa*. Responses showed that this knowledge is still commonly used in the communities where this research took place. 60% of the Maya farmers who took part in the survey mentioned that they always use indigenous knowledge in numerous forms in their agricultural systems, while 11% indicated that they no longer use it (Figure 4.5).

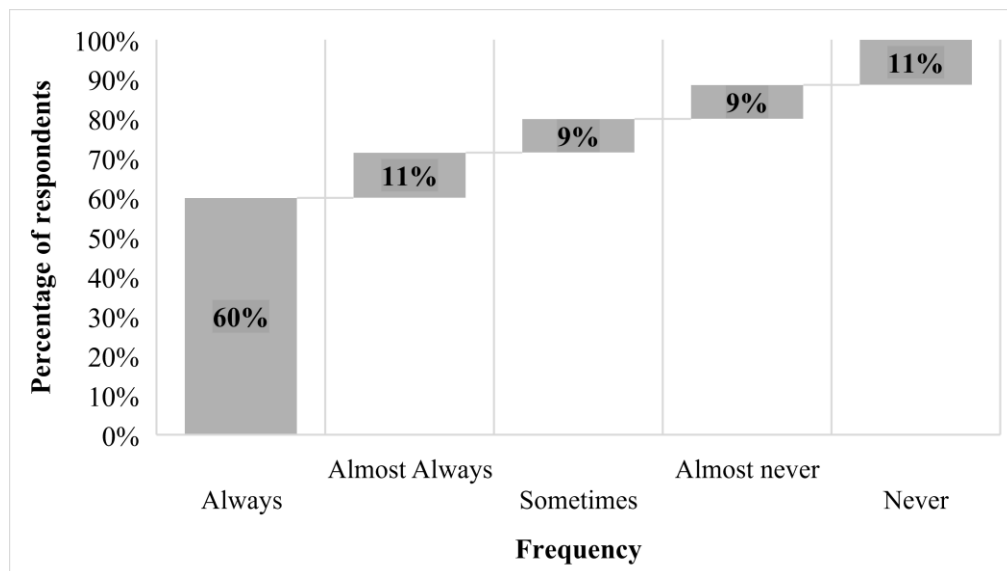


Figure 5.5. Frequency in the use of indigenous knowledge by Maya milperos in Mexico and Belize.

Among the main reasons mentioned for still using these forms of indigenous knowledge were mostly that they work (functionality), and are needed for *milpa* to produce yield, but it was also mentioned that they are necessary for protection, to show respect and to give thanks to the *monte*:

“Because they work, if not used then you don’t harvest”

Farmer, Patchakan Community,
Corozal, Belize

“Because it works, if one plants wrongly with the moon, you only get leaves.”

Farmer, San Antonio Community,
Cayo, Belize

“Because it is the tradition that we have here...To give thanks for what the milpa provides to us”

Farmer, Ejido Xoy,
Yucatan, Mexico

“To give thanks to the forest for giving us good yield and for the land to be more fertile”

Farmer, Ejido Tzucacab,
Yucatan, Belize

Furthermore, 89% of all the farmers surveyed considered indigenous knowledge as important, even amongst those who stated that they almost never use it. Amongst the reasons given for these elements to continue being used, four were highlighted and align with those reported by other authors. These were: a) association with high and better yields (Arias et al., 1995; Terán and Rasmussen, 1994); b) to maintain traditions of their ancestors and their cultural identity (Tuz Chi, 2010); c) for self -subsistence (S. Terán & Rasmussen, 1994) and d) as a symbol of respect to nature/*monte* (Tuz Chi 2010). These reasons highlighted that indigenous knowledge within the contemporary *milpa* in these communities, is not just another cultural element as it is often considered by modern science, but an integral, flexible and continuing way of being that influences the development of multiple resilience schemes of their own.

In understanding the use of indigenous knowledge, a diverse range of cultural elements essential for “making *milpa*” were identified amongst participants in Mexico and Belize. Some elements documented were considered just a necessary practice to achieve productivity, while others were considered an essential part of their identity and cultural life and are rooted on pre-Hispanic and post-colonial religious elements and on their relationship with the *monte*.

This relationship was described by Thompson (1979) highlighting that in Maya societies one of the aspects of their daily life is founded on a “sacred contract of reciprocity” between people and the powers of nature which must be recognized and remunerated. Garcia-Quintanilla (2000) contributes to this discussion by mentioning that rituals play an essential role for guaranteeing protection, food and health. Terán & Rasmussen (1994) provided a complete description of this “reciprocity-gratitude” relationship by mentioning that milperos in Xocen, Yucatan continue performing these rituals mostly because the reciprocity, or the lack of it, can influence environmental elements which are important for *milpa* “they feel completely in the hands of God and the supernatural beings who, according to them, control the rain and plagues. In case of misconduct by the peasants, the gods can punish the sinners and stop the water, send “bad” rains, hurricanes or plagues. Under these conditions, the peasants have no choice but to beg for water and the removal of predators”.

This conception of reciprocity-gratitude and punishment was also observed in this research during the interviews and participant observation conducted in 2021 by a farmer in Xoy and a farmer in Oxkintok in Yucatan:

“You realize how it works when the prayers are made. I have seen that for example people who make their primicia (offering) in the milpa, sometimes the people who are next to them sometimes have their milpa destroyed by the animals just by not making those offerings so sometimes you realize the reason for the offerings or the primicias”

Farm 4, Xoy, 2021)

“The loo ritual is an exchange is called a trade-off, if the earth offers me, I offer something in return to the earth, it is a reciprocity so to speak. To the earth for having given me a good harvest I offer her an offering in gratitude that she has given me a good harvest”

Farm 2, Oxkintok, 2021).

When comparing between case studies to see which indigenous knowledges (See Table 5) were predominantly still used amongst Maya Yucatec farmers, results showed that in both countries, moon phases were the knowledge learnt and used by everyone except one farmer.

Farmers in Mexico reported learning about Maya rituals and beliefs including those related to “nature/*monte* reciprocity” (U janli kool, Loo), protection (Sakaa’b, Prayers to Jesus Christ), good yields (moon phases) and environment elements (Xookin, Cha’ chaak, Bio-indicators) though only currently used by two of the farmers. In Belize, farmers use of indigenous knowledge was associated more with beliefs that assure the production of good yields (moon phases), without much consideration of “nature/*monte* reciprocity”, hence why this indigenous knowledge showed to be practiced by three out of four farmers (Table 4.3).

Table 5.3. Indigenous knowledge reported to be learnt and used by each farmer in Mexico (MX) and Belize (BZ).

	MEXICO				BELIZE			
	F1 Mx	F2 Mx	F3 Mx	F4 Mx	F5 Bz	F6 Bz	F7 Bz	F8 Bz
Xookin (Cabanuelas-Annual weather forecast)	●	●		●				●
Cha cha'ak (Rain petition ceremony)		●		●		●		
Loo (Trade-off ritual)		●						
Wuaji Kool (Thanksgiving offerings)			●	●		●		
Sa'akaab (Permission to the forest)		●	●	●				
Moon Phases	●	●	●	●	●	●	●	●
Prayers to God (Jesus)						●		
Bioindicators				●			●	
● Learnt and still practicing ● Learnt but no longer practiced								

In the case of Farm 6 in Belize although the family still speaks Maya and the language is being transmitted to younger generations, in terms of agricultural management indigenous knowledge is no longer used. This is because the eldest member (who was interviewed for this study) was exposed at a very young age to modern techniques used by foreigners (from the United States) and Mennonites and his priority has been towards advanced agriculture. Therefore, IK was learnt, but is no longer practiced nor transmitted for management purposes, yet still used in other aspects of agriculture (name of soils or maize varieties) and in aspects of their daily life (health and food).

Results from the surveys conducted among Maya milperos in Mexico and Belize show the different forms of indigenous knowledge used across both countries (Figure 4.6). In Belize the belief around moon phases was the most common indigenous knowledge used within the *milpa* which is related with better productivity and good yields and has nothing

to do with a direct relationship with the *monte*. In contrast in Mexico the most common indigenous knowledge were rituals specifically the Sakaa'b (see Table 4.3) followed by the *primicias* (offerings). Both rituals involve the so called “sacred contract of reciprocity” between people and nature mentioned previously.

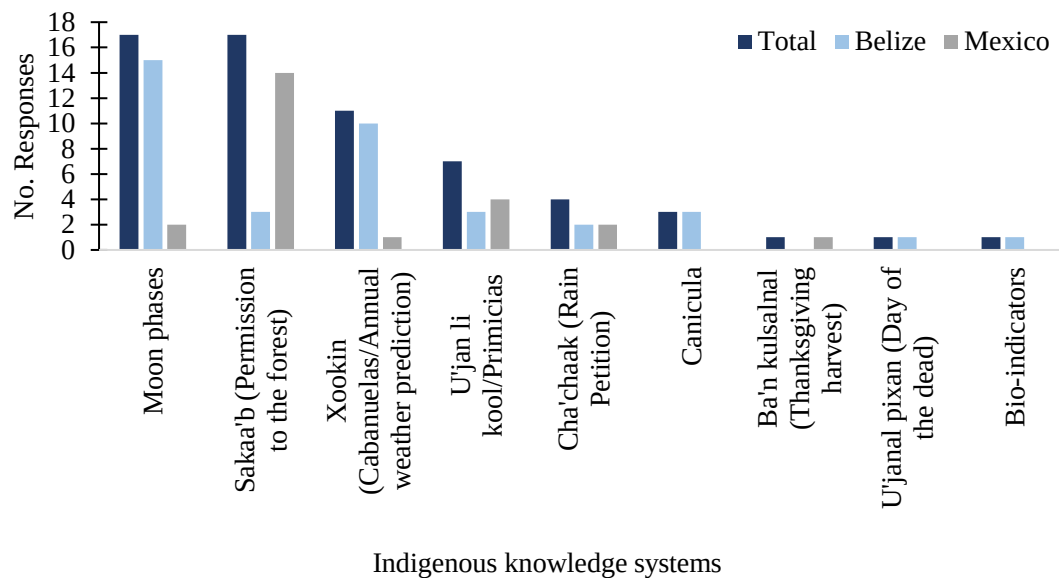


Figure 5.6. Types of indigenous knowledge associated to *milpa* and frequency of usage according to farmers in Mexico and Belize (N=35).

Understanding different indigenous knowledge systems was important for the research as it provided a detailed description of how local knowledge is prioritised among the same cultural group and reinforced the arguments of Cahuich-Campos et al. (2014, p. 180) who stated that when studying agrobiodiversity systems like *milpa* it is important to “strengthen worldviews and cultural identity of contemporary societies like Maya Yucatec and consider a revaluation of cultural and biological heritage, vindicating cultural heterogeneity and opposing the global vision that seeks to standardize the needs of human groups”.

How *milpa* is perceived both physically and culturally was important to further analysing how the dynamic change of *milpa* can influence the use of knowledge systems within the *milpa*.

4.3. Changes within the Maya *Milpa* in Mexico and Belize and its impacts in knowledge systems

4.3.1. Main changes observed in the Maya *Milpa*

Changes in the *milpa* and the impact in knowledge systems was also subject of study in this research. Participants of the case study analysis were asked to free list changes observed in the *milpa* system from when they started to practice *milpa* until now (Table 8). Thematic analysis showed that six main changes were reported and were portrayed around traditions, management, environmental conditions, economy and yields, health and human population growth.

Table 5.4. Changes observed across time in the *milpa* system reported by case studies in Mexico and Belize

Case Study Data	Country	MEXICO				BELIZE			
	Farm ID	F1MX	F2MX	F3MX	F4MX	F5BZ	F6BZ	F7BZ	F8BZ
	Age of Farmer	72	55	65	45	35	70	36	42
	Year farmer started practicing <i>milpa</i>	1955	1975	1964	1988	1995	1959	2000	1997
Changes	Traditions		•	•	•			•	
	Management		•	•	•	•	•	•	•
	Environment/ Biophysical Conditions	•	•	•	•	•	•	•	•
	Economy/ Yields		•			•	•	•	
	Health						•		
	Human Growth and Development						•		

Similar questions asked during the surveys highlighted that the main changes perceived by Maya Yucatec farmers were in terms of management, environmental conditions and economy/yield productivity (Figure 4.7). In all but one community (Tzucacab), management was portrayed as a common perceived changed. Similarly, in all but one community (Maxcanu) economy/yield productivity was also highlighted as one of the main changes. In relation to environmental conditions four out of the six communities

indicated that conditions have changed. An interesting view was observed around changes in traditions as only half of the studied communities consider that there have been changes in tradition, and among those the proportion of farmers who perceive that traditions have changed was low (only 5 farmers out of 35).

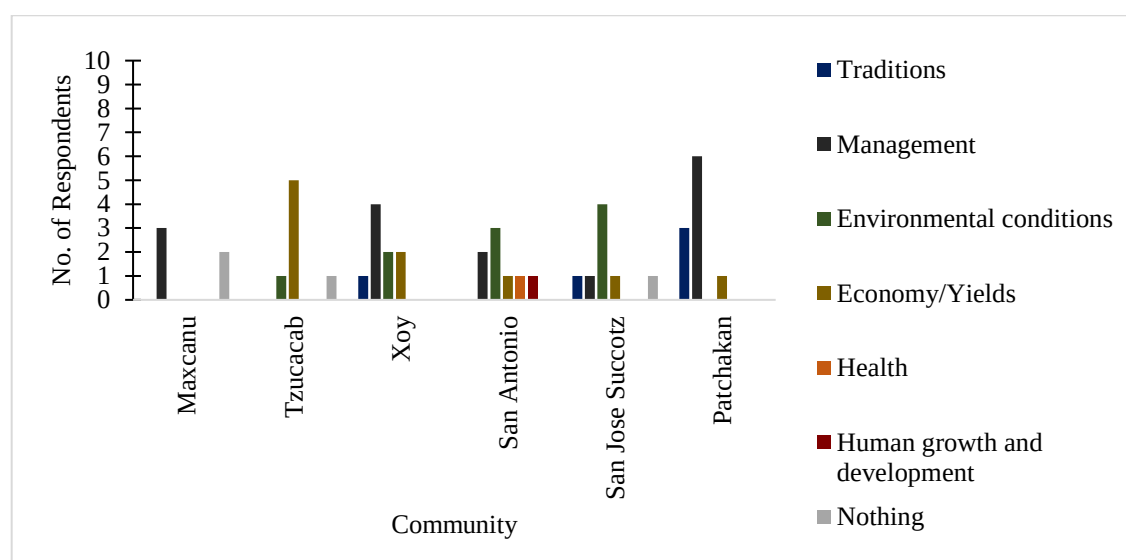


Figure 5.7. Frequency of responses in relation to the most noticeable changes that have occurred in the *milpa* system based on a survey conducted in six communities in Mexico and Belize (N=35).

A secondary thematic analysis amongst case studies allowed specific changes (past and present) to be identified within the main themes and were further compared to those mentioned in the surveys. This allowed the identification of what specific conditions have changed and how these have impacted the *milpa* system and consequently ways of knowing which are shown within the next subchapters.

4.3.2. Changes in management

In terms of management, the secondary thematic analysis showed that six main specific changes have been observed in *milpa*: planting times, crop diversification, irrigation, storage, use of chemicals, planting techniques and changes in seed varieties. These changes can also be observed in the way of using knowledge. Out of these six changes, use of chemicals which was associated to pest control and fertilization was the most common change reported by farmers.

When looking at the use of knowledge systems (indigenous vs modern/technical knowledge) by participants in relation to *milpa* management (Figure 4.8), IK continues

to be used in both countries for most of the management activities. However, when analysed by country, Belize relies almost fully on modern/technical knowledge for the management of *milpa* in relation to pest control and fertilization, whereas in Mexico farmers still use indigenous knowledge for fertilization, and pest control. There is a slightly higher use of modern/technical for pest control compared to other management activities, but minimal compared to that used by farmers in Belize.

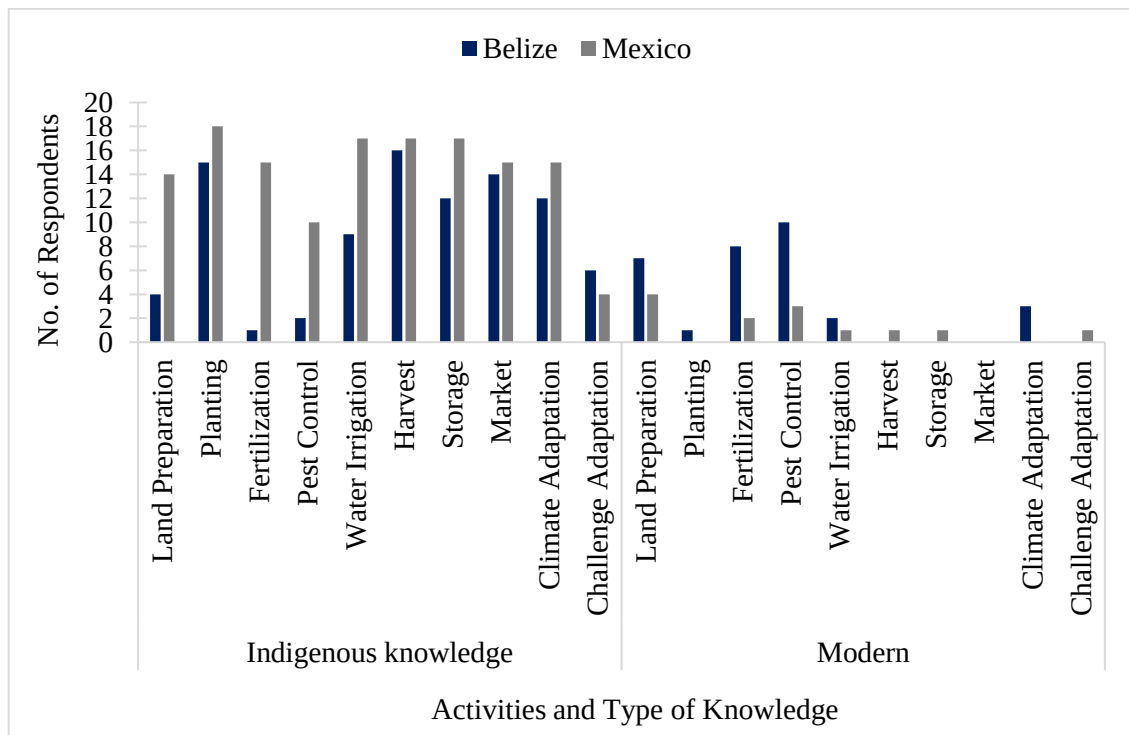


Figure 5.8. Use of knowledge systems within *milpa* management reported by farmers in Mexico and Belize.

4.3.3. Changes in biophysical conditions.

Even though only 10 farmers out of 35 reported that environmental conditions have changed, participants reported that changes in management have occurred because of changes in environmental/biophysical conditions which in their views resulted in changes in knowledge systems. Reports of these changes provided evidence of the multiple interlinked impacts across the *milpa* system, that have been reported in other socio-ecological systems (Falardeau et al., 2022).

The main changes in environmental conditions reported by participants showed that a) general changes in weather, b) rain variability, c) drought, d) heat, e) increased pests and f) environmental regulations were some of the most visible changes witnessed in both

Mexico and Belize. Within this, pests and changes in weather were changes identified in four out of six of the communities surveyed. Participants also reported that the impact of these changes was reflected in yields and considered by participants as another of the main changes observed in the *milpa* system. It is not surprising then that when specifically examined in the case studies, overall traditions, management, environmental conditions and economy/yields, were described by four out of six farmers in Mexico and Belize as some of the changes observed in the *milpa* system across time.

Since traditional *milpa* relies on soil and climate to survive, changes in biophysical conditions are threatening and have changed the relationship of Maya milperos with the *monte* and embedded indigenous knowledge. They are also modifying the way farmers overcome vulnerability to these environmental conditions (Cahuich-Campos, 2014), while driving the loss of detailed information provided through indigenous methods and practices that most of the time modern scientific methods cannot provide.

An example of the impact of changes in biophysical conditions over cultural dynamics is seen in one of the rituals that continues to be performed: the Cha'Chaak (rain petition ceremony, see Table 5). This ritual is carried out by a Maya priest (*H'men* in maya) who acts as a mediator between milperos and supernatural forces present in the *monte* to ask forgiveness to the *monte* for being “altered” by farmers and prays for rain to come (Garcia-Quintanilla, 2000). However, rainfall variability has indirectly affected the time period when this ritual was practiced (between March and May) and has been adapted to the new rainfall periods (May or June; Poot 2021, personal communication).

Because indigenous knowledge develops through experience and is transmitted across generations, changes in elements that are fundamental to a way of knowing can cause a rupture of the transmission system (Iniesta-Arandia et al., 2015). In the case of the Maya *milpa* system, changes in biophysical conditions are affecting rituals (like the Cha' chaak) that are part of the social and cultural dynamics of the Maya people (observing nature), which eventually can cause a “de-structuring of the social community and the embedded knowledge” according to Iniesta-Arandia et al. (2015). Although not evident in the studied communities, farmers did express concern about the risk of disappearance of this ritual or beliefs (such as the reliance on bioindicators for weather prediction) as a result of climate variability (Chapter 6).

4.3.4. Changes in the processes of transmission and acquisition of knowledge

The transmission and acquisition of *milpa* knowledge in the Maya communities studied appeared to have changed, providing additional evidence of why the relationship with the *monte* and the connection to worldviews and knowledges has also changed. Maya farmers in Mexico and Belize reported changes in the way knowledge was acquired in the past and how they currently acquire new knowledge (Figure 4.9).

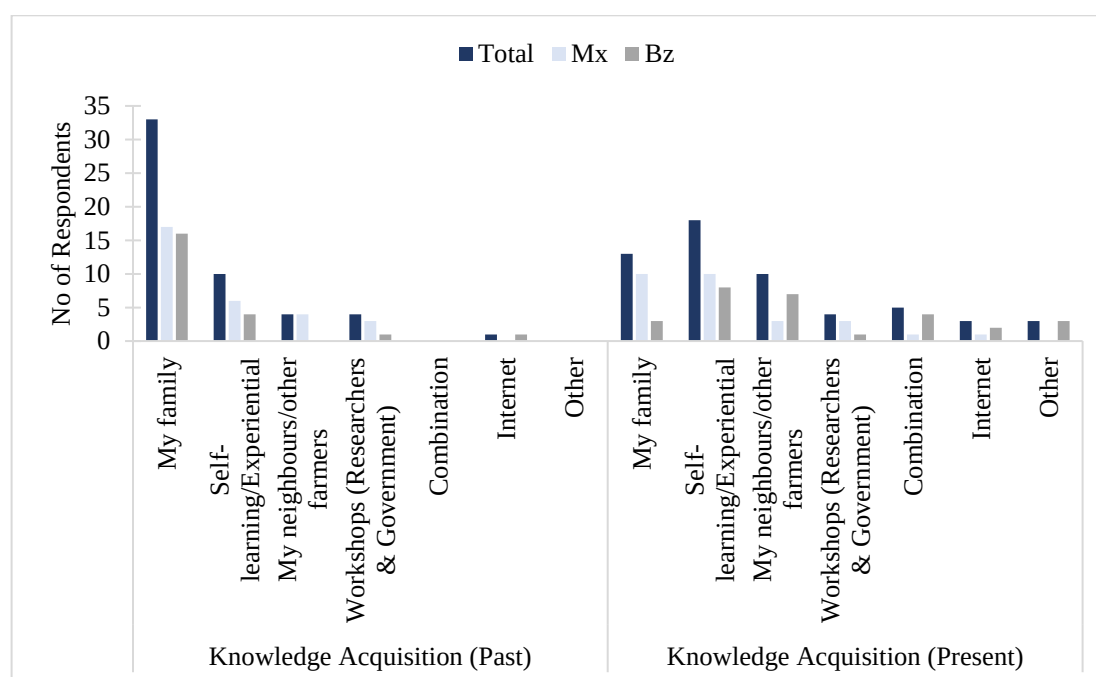


Figure 5.9. Changes in how knowledge used to be transmitted compared to how contemporary knowledge is transmitted and reported by Maya farmers in Mexico and Belize.

In both countries the knowledge acquisition used to be done mainly through family; within this the main transmitter was the father (56%), followed by self-learning by watching and practicing (experiential learning; 18%) and learning from another family member (14%).

In both countries, reliance on family for knowledge acquisition and transmission has diminished and although currently in Mexico family continues to be the main source of knowledge acquisition, there has been a substantial increase in self-learning.

In Belize, there is also evidence of breakdown of intra- and intergenerational relationships (Davidson-Hunt & Berkes, 2003) since knowledge is now mostly acquired through self-learning/experiential and neighbours (who often have exposure to “innovative and technological” practices) and almost none through family. This, as

reported by Gómez-Baggethun and Reyes-García (2013), is affecting the maintenance of indigenous knowledge in Belize, but also the capacity of new generations to “generate, transform, and transmit knowledge” which in addition to the dominant modern discourse of productivity and development they are subject to, is causing a “break of historical links between ecosystems and social systems” (Iniesta-Arandia et al., 2015) which translates into a less connection to worldviews and knowledge embedded in this linkage (such as the attachment to the *monte*).

New generations though continue to be interested in learning about the *milpa*, the study shows that 67% of farmer’s young family members are learning about the *milpa* vs 33% that are not learning. Those who are learning are doing it by watching and practicing (direct observation; 88%), watching others but not practicing (4%), watching others and through formal studies such as agricultural sciences (4%) and through workshops or training (4%).

In both countries the results from the surveys, interviews and participant observation portrayed that learning about *milpa* (compared to the past) currently doesn’t only involve learning the indigenous knowledge, but also modern globalised science, however this has played a significant role in the life of Maya Yucatec people in cultural adaptation.

4.4. Implications of modern globalised science (western knowledge) on indigenous knowledge

In studying changes in indigenous knowledge systems Akena (2012, p. 606) argues that it is important to understand “the connection between societies, history and knowledge production” especially in relation to modern globalized science (Western knowledge). The author also argues that to understand the changes and marginalization of indigenous knowledge systems is important to examine the role of modern globalised science on this process. This is particularly important in communities like those in Mexico and Belize who have had a historical relationship with different non-indigenous stakeholders given that “when knowledge produced by external actors is imposed on an indigenous cosmology it tends to undermine the norm, values and gendered contexts...and becomes disempowering and colonizing” (Akena 2012, p. 606) as it appeared to be the case in the studied communities according to the farmer’s narratives.

It is important then to “examine the knowledge producers and their social, economic and political positions within colonial contexts” Akena (2012, p. 600). Sharma (2021, p. 29) clarifies that “critiques to western discourses in knowledge production are not aimed at rejecting modern science, or to deny the wonderful technological advancements made, but to situate modern science in the context of the diversity of knowledges existing in contemporary societies” and to address issues of epistemic inequality that might be indirectly influencing cultural adaptation and changes to indigenous knowledge systems.

4.4.1. Dismissal of indigenous knowledge and cultural adaptation

Results from the surveys and the case study analysis (for methods see Section 4.3) showed that reduction or dismissal of indigenous knowledge systems by external actors appeared to be a common perception in both countries; forcing farmers to shape their own cultural frameworks into western frameworks and epistemes (Doxtater, 2004; Whyte et al., 2018). In doing this, indigenous knowledge principles have been dismissed and the preservation and transfer of their knowledge threatened, fragmented and modified resulting eventually in loss or changes to Maya indigenous knowledge systems (Akena, 2012; Simpson, 2004).

In both countries, it appears that because epistemology of indigenous knowledge hasn't been recognised and is often dismissed, a form of *emancipatory interculturality* (Contreras-Reyes & Calles-Naveda, 2020; de Sousa Santos, 2016) has occurred in the Maya *milpa* system as part of its transformation. Emancipatory interculturality according to Contreras-Reyes and Calles-Naveda (2020, p. 32) “encourages new processes, practices and strategies of intellectual intervention, which could include, among others, the revitalization, revaluation and application of knowledge ancestral, but not as something linked to a locality and temporality of the past, but as knowledge that has contemporaneity to critically read the world, and to understand, (re)learn and act in the present”.

For the Maya Yucatec farmers in Mexico and Belize this emancipatory interculturality has involved a cultural adaptation with a “recognition of a plurality of knowledges and distinct conceptions of the world” (de Sousa Santos, 2016, p. 200). In doing this, modern globalised science and indigenous knowledge are recognised and used by Maya Yucatec farmers, but have led to a “constant reconstruction of identity discourses” (de Sousa

Santos, 2016, p. 200), including the way indigenous knowledge is prioritised, learnt, shaped and transmitted.

This process is, therefore, leading members of the same cultural group (Maya Yucatec) to have a variety of responses and priorities; but is also having implications for identity, self-determination and knowledge preservation (Nakata, 2002, 2007). As a result of this involuntary cultural adaptation, new ways of conceptualizing not only worldviews, beliefs and agricultural practices but also local elements within their territories such as climate, environment and society are being adopted (Nightingale et al., 2020).

Cultural adaptation in the context of the Maya *milpa* is of interest given its impact on the contemporary ways of learning new knowledge. Within this study four types of learning were identified to be prioritised currently by farmers and are like those reported in indigenous groups in the Peruvian Amazon (Aikman, 2019). Overall, the main current ways of learning that emerged from surveys were: experiential learning (28%); learning from family (including traditions, cosmology and ways of life; 22%); learning from neighbours (replicate system; 17%) and learning through involvement in training/capacity building with external institutions (local government/extension services/research centres/agro-businesses; 15%; Figure 4.10).

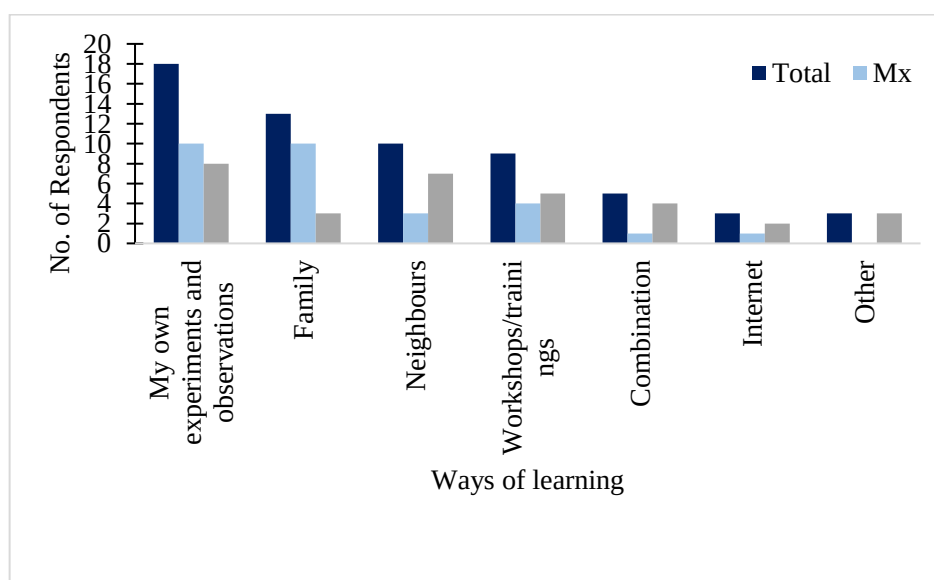


Figure 5.10. Frequency of responses in relation to the main current ways of learning reported by Maya Yucatec farmers in Mexico and Belize.

Although in both countries there is exposure to modern globalized science mostly through training and workshops, this is more evident in Belize given that there is a well-established extension service from the government. Farmers in Mexico have no access to an extension service, although they do have access to government agro-programmes (but not all of them involve capacity building) and some of them also collaborate with research centres. Government agro-programmes are mostly focused on providing monetary support or incentives for agricultural inputs. Access to capacity building comes from either workshops provided by research institutions or emerging government programmes like Sembrando Vida (“Sowing Life”; See 2.4.2), which not all of them can, or want, to access given that practices tend to be decontextualized and tends to undermine indigenous practices and local contexts. As a result, farmers continue to rely mostly on their experiential and family learning processes.

In Mexico the cultural adaptation within Maya Yucatec farmers is shaped by a knowledge system mostly rooted in indigenous epistemologies but integrating some modern globalized science that could enhance their local interests, a similar posture adopted by Maya people during post-colonialism aimed to prevent the erasure of cultural identity.

In Belize Yucatec farmers’ cultural adaptation and ways of knowing, being and acting are shaped by a social landscape built and dominated under a power-knowledge relation (Barnes et al., 2013, Bernard et al., 2014; Doxtater, 2004) which unfortunately has had a tendency towards dismissing indigenous knowledge and consequently has influenced farmers’ behaviour around productivity through the adoption of more globalised/western knowledge discourses (Feola et al., 2015).

4.4.2. Indigenous knowledge marginalization, dominant discourses and power relations as drivers of change in *milpa* agriculture.

Perception around the marginalization of cultural elements in the *milpa* system was portrayed during the surveys, despite being relevant elements in farmer’s livelihoods. 92% percent of the farmers surveyed mentioned that their knowledge and traditions should *always* or *almost always* be considered by external actors that work directly with them, since it is part of their identity and their cultural heritage, but this doesn’t necessarily occur in practice.

Farmers explained that external actors working in their communities have shown a lack of interest or have referred to their knowledge as useless or outdated. Indigenous knowledge systems have often been considered as a complementary element within systems aimed to produce food and generate income, rather than as a primary and essential part of farmers' traditional lives and way of being, therefore often considered as less relevant, old or less productive (Cahuich-Campos et al., 2014; Muller, 2012; Rajasekaran, 1993). Garcia-Quintanilla (2000, p. 282) explores this argument by explaining that “the rituals and attitudes of the milperos towards the forest and in general towards the resources have appeared—to foreign eyes—as meaningless, as totally superfluous issues and lack of logic.” This perception was captured during the surveys and interviews conducted in Mexico and Belize and aligns with those recorded with small-scale farmers in India and Vanuatu working with agricultural researchers and extension personnel (Rajasekaran, 1993; Rarai et al., 2022).

When analysing this perception by country, in Belize farmers expressed that one of the reasons for not using indigenous knowledge as before was because it is often considered as outdated by the government's agricultural extension service. In Mexico this perception varied depending on the community and the external actors involved. Farmers from different communities but working with the same research centre (International Maize and Wheat Improvement Center/CIMMYT), had different opinions about the value and respect of indigenous knowledge. While one (Farm 4) admitted that they didn't value their knowledge, another farmer (Farm 2) stated that they did and that they prioritized it. However, this same farmer (Farm 2) admitted that a government incentive programme to implement agroforestry activities (known as *Sembrando Vida* or *Sowing Life*) does not value their knowledge and has imposed techniques that are decontextualized from their native territories and narratives.

These techniques and dominant modern globalised discourses are displacing and changing the traditional way of practicing *milpa* according to farmers. Narratives portrayed by farmers (Table 4.5) also suggested that they are often exposed to polarised discourses over the validity of certain knowledges which have impacted the perception and appropriation of Maya Yucatec indigenous societies within their territory and which have influenced how farmers response to certain circumstances (e.g. Climate change; Vázquez González et al., 2018b).

Table 5.5. Narratives of Maya Yucatec farmers in Mexico and Belize in relation to consideration of indigenous knowledge in *milpa* system by external actors.

About Extension Programme- Ministry of Agriculture (Belize)	<i>“The problem is the traditional, those that are more knowledgeable, they don’t think it can work and they say that this is not how is done.”</i> Farmer, San Antonio Community, Belize
	<i>“You cannot say anything because is an offence to their “knowledge” “</i> Farmer, San Jose Succotz Community, Belize
	<i>“They should respect it because they are native things from our ancestors”</i> Farmer, Patchakan Community, Belize
About CIMMYT (Mexico)	<i>“I think they don’t value them because at one point they say they are, the moment they are with you they say yes but then they are forgotten, and I think they don’t even pay attention to those traditions.”</i> Farm 4, Xoy, Mexico
	<i>“Yes, they respect it because in fact they consider our traditions first and then just simply ask us to apply the new techniques to be able to make the most of the plants.”</i> Farm 2, Oxkintok, Mexico)
About Sembrando Vida Programme (Mexico)	<i>“It is completely out of context and no they don’t respect it; they impose a certain cultivation technique on us that we see does not work but guidelines must be followed. Their techniques are imposed on us, we suffer it, we are not used to doing it like this.”</i> Farm 2, Oxkintok, MX)

Narratives from farmers, together with evidence collected through surveys, suggest that in both countries, there is a dominant knowledge that is prioritised by Maya Yucatec Farmers (either indigenous or modern) which influences their decision making, adaptation practices, ways of being and acting but also their social and cultural identity (Frank et al., 2011).

A combination of external and internal factors has influenced the relationship of farmers with their indigenous knowledge and consequently with their perception of *milpa*, the way *milpa* it is characterized and structured and therefore with how it is valued by farmers and could explain why *milpa* is constantly adapting and changing.

Attachment to *milpa* and to certain knowledge appears to be limited not only to historical and cultural elements, which has been widely explored in the present chapter, but also to local biophysical conditions and which can also shape how knowledge is used and adapted particularly in the context of climate change. Having presented a context and

reflection of the current state of *milpa* in both countries and elements influencing changes in both *milpa* and knowledge, the following two chapters focus on the characterization of two physical elements that are relevant to *milpa* and to knowledge adaptation: Soil and Weather.

CHAPTER 5 Integrated approaches to soil quality in traditional agricultural systems in Mexico and Belize

5.1 Introduction: Soil and climate change

Soil is a multifunctional component essential for life, but little attention has been paid to it as part of *milpa* management even though it plays a crucial role in ecosystem functions and services and consequently in its ability to support humans and animals (Brady and Weil, 2008 Pozza & Field, 2020). Soil is commonly associated with plant growth, but several authors have distinguished a variety of functions (Bouma and McBratney, 2013; Koch et al., 2013; Pozza and Field, 2020). A report from the Royal Society (2020) listed the main ecological functions of soil as follows: 1) plant growth medium; 2) nutrient recycling system; 3) habitat for living organisms; 4) water purification and supply system and flood prevention; 5) support for human infrastructure development and 6) climate change mitigation through carbon sequestration.

In agriculture and food security, soil plays a crucial role since its functionality determines society's ability to produce food (Koch et al., 2013). It is estimated that around 95% of the world's food supply relies on soil functionality (FAO, 2015). Benefits and functionality of soil are linked to its structure (Royal Society, 2020), however, changes in climate can threaten this structure and hence soil processes and properties (Brevik, 2013; Howden et al. 2007; Havlin et al., 2014). Soils and climate are connected through the carbon, nitrogen and hydrological cycles (Brevik, 2013). As a result of this interaction, when variations in environmental and atmospheric conditions occur recurrently, they can directly impact soil natural processes and properties (Brevik, 2013).

Expansion and intensification of agricultural practices can contribute to an increase in soil stresses often causing soil degradation and reducing crop yield potential. Soil stresses are often related to plant available water, temperature, and nutrient availability (Havlin et al., 2014) and can vary depending on the region, the microclimate, and management. A decline of soil functionality and subsequently of soil health and productivity can jeopardize food security across the globe, thus increasing the risk of a shortage in food supply.

Considering the above, an understanding of the interactions between climate and soil is necessary, particularly in rainfed agricultural systems like *milpa*, to identify how these

interactions, together with management, can impact soil structure and the potential consequences for local food systems. Interactions between climate and soil quality are often studied through scientific analysis but not as frequently in *milpa* despite being highly sensitive to climate variability (Brevik, 2013; Howden et al., 2007). Understanding these interactions can help to implement better local adaptation strategies and policies that are useful for farmers and beneficial for food and soil security.

In traditional agro-food systems like *milpa*, aside from scientific analysis, knowledge, perception and management of soil quality by farmers should be considered as they also play an important role when understanding soil quality. According to De Souza et al. (2016, p.2) bridging of knowledges is crucial given that traditional agro-food systems “are considered to be the result of social structures and processes involved in farming interacting with the local ecosystem” and can be very beneficial to address challenges to food security and build resilience to different challenges as well. Farmers’ knowledge is, however, often dismissed because of differences in epistemologies in worldviews (Chambers, 2005; See Chapter 2, section 2.1).

Different authors have stated that soil is a social ecological system in agriculture which has both a natural capital, where stocks can be assessed by scientific methods, and a local human capital consisting of knowledge, actions, and capacities learnt across time by different means around manageable soil properties related to production (CGIAR, 2014; Dominati, 2013; Mc Bratney et al., 2014). As a result, decision making affecting production is based on perception and knowledge of soil quality and is according to De Souza et al. (2016, p. 4) “central to the human capital brought to bear on the evaluation of soil quality and soil productive capacity”. Understanding soil quality then requires understanding of the natural and human capital of soils in Maya *milpa* systems by bridging scientific and indigenous worldviews.

A first approach to this was to consider management practices in *milpa* plots in Yucatan (Mexico) and Belize and further examine the characteristics and properties of local soils based on land use management. Throughout this process it was important to identify how farmers evaluate soils and how this compares to scientific analyses. Integrated approaches are important in systems like the Maya *milpa* where traditional classification of soil attributes is currently used and where this is part of the farmers daily decision-making process.

Assessing soil quality of *milpa* plots managed under different techniques through measurable characteristics (organic matter, texture and particle size distribution, nutrient availability and pH; see Chapter 3; Section 3.8.2.1) provided a scientific overview of the local soil conditions. It also contributed to understanding better the relationship between farmers and their own environment in relation to soil and what specific properties and knowledges are prioritised. This approach contributed to the discussion around the importance of participatory governance where according to Blum (2005, p. 79) “all people living in a given area or space should decide which soil functions they will use (prioritise) at a given time and/or at a given space”.

5.2 Contemporary management practices in *milpa* within Yucatan and Belize.

A first approach to understanding soil functionality in modern agricultural *milpa* in Mexico and Belize was to describe and get understanding of the current management in each studied plot (Table 5.1). As described in Chapter 4; Section 4.2.1.1, *milpa* management is mostly influenced by market and financial drivers and to some extent by food security in the case of Belize and by food security and cultural identity in the case of Mexico. These drivers are then influencing decision-making related to plot management that are impacting soil properties. Management can then vary significantly from one farm to another thus impacting soil fertility and consequently the capacity of soil to function properly.

Table 6.1. General managerial characteristics of eight studied farms in Yucatan (Y) and Belize (B)

<i>Farm ID</i>	<i>Land management</i>	<i>Crops associated</i>	<i>Type of maize</i>	<i>Fertilization</i>	<i>Irrigation</i>	<i>Other</i>
FARM1-HST (Y)	Intercropped	Beans	Improved and Local	Biofertilization	Rainfed	Herbicides (weed control)
FARM2-LM (Y)	Intercropped	Beans and Squash	Local	Biofertilization	Rainfed	Herbicides (weed control)
FARM3-LNXY (Y)	Intercropped	Squash	Improved and Local	Chemical	Rainfed	Herbicides (weed control)
FARM4-LGR (Y)	Intercropped	Beans, squash and Sweet potato	Local	Biofertilization and occasionally chemical	Rainfed	Not specified
FARM5-HY (B)	Rotation	Vegetables	Hybrid	Chemical and Biofertilization (Chicken compost and Lime)	Rainfed and Irrigation	Herbicides (weed control)
FARM6-LY (B)	Rotation	Vegetables	Local	Chemical and Biofertilization (Manure)	Rainfed and Irrigation	Herbicides (weed control)
FARM7-HY (B)	Continuous	Monoculture	Hybrid	Chemical and Biofertilizer (Chicken Manure)	Rainfed	Herbicides (weed control)
FARM8-HL (B)	Rotation	Vegetables	Local and Hybrid	Chemical and Biofertilization	Rainfed and Irrigation	Herbicides (weed control)

Records of the management practices showed that *milpa* systems in Mexico differed from those in Belize mainly in terms of land management, fertilizer use and irrigation. These practices are determined by the priorities of each farmer in each country and has impacted their decision making around how to adapt the agricultural system; but also, when choosing which knowledge to use in specific management activities.

The main management strategy in all studied plots in Mexico consisted of intercropping maize (mostly native) with two or more crops (mostly legumes). In Belize three of the studied plots were managed through crop rotation processes across seasons, with maize (hybrid and local) in rotation with different vegetables dominating the crop system; one plot (Farm 7-HY) was found to be continuous monoculture (monocropping) with hybrid maize (See 4.2.1.1). The way each of the plots is structured and managed is the result of the farmers perception around soil quality and functionality influenced by social, cultural and economic drivers. This aligned with findings from De Souza et al. (2016, p. 9) with farmers in Brazil whose perception is “rooted in the history of the socio-cultural landscape, which reflects issues of long-term socio-economic viability of the local agro-ecosystem”. In the case of farmers in Belize and Mexico the perception of farmers around soil quality and functionality is also a driver for decision-making that has directly affected how *milpa* is perceived managed and adapted.

In terms of irrigation, studied plots in Mexico were all rainfed. In the continuous monocrop plot in Belize the system was also rainfed, however in the other three studied plots in Belize, the irrigation system varied depending on which season (summer or winter) maize and vegetables were grown. In Belize, when vegetables are grown within the plots, the soil is irrigated through mechanized irrigation, however when maize is cultivated the land is still managed as rainfed.

Farmers in Belize who grow local/native seeds explained that the reason to keep using rainfed irrigation, despite having mechanized irrigation, is because when planting local/native maize seeds these can only be grown rainfed and at specific times during the year (May-June), an observation also pointed out by farmers in Mexico. This portrayed the local human capital of farmers consisting of knowledge about soil functionality regarding native varieties and the influence of climate conditions over it.

“That type of Creole (local) maize has its season, because if you sow it, it must be done by May, at the latest in mid-June, and if you sow after June, when July begins, if it blooms, it grows, and develops, but it just goes up, you don't get cobs and if there are cobs, they grow without grains. This is due because of the season and soil...on the other hand, the hybrid gives you whenever you want to sow as long as you have water.”

Farm1HST, Maxcanu, Mexico, 2021

“Well, you know, speaking of maize, what I have learned the most since I was little, we have a date more or less, of when we are going to clean the plot, when we are going to burn the milpa and when it must rain. And we have until a specific date we know when it is the last day, that the local varieties can be planted. So, the local varieties as far as I remember are planted for Saint John, that it is June 24th. After June 24th, if we plant we have experienced that the harvest it is not the same, it gives less and the maize cob does not fill up I do not know why, but I can tell you from experience that we have observed it, we have verified it”

Farm8HL, Patchakan, Belize, 2021

An important consideration when documenting management was to fertilization since it can affect organic matter content, as well as nutrient availability and can provide a good indication of soil quality. This is particularly important in intercropped and rotation systems since different crops require different nutrients and so a diversified fertilization is implemented which can impact soil properties. Fertilization in Belize and Mexico is often biological/organic, chemical or combined (chemical and biofertilization) according to participant observation however, biological and combined fertilization were more common than chemical. Farms 1, 2 and 4 in Mexico used biological fertilizer with slash and mulch, animal manure, neem and biol (microorganism preparations) amongst the most used. Reasons given for the use of this type of fertilization were the high costs of commercial agricultural inputs and a lack of stable financial resources to cover such costs, in addition to a shared concern about the consequences of “poisoning the land” and health impacts. Farm 3 reported use of chemical fertilizer was mostly used due to having access to government social programmes that give access to inputs such as fertilizer at a lower cost and being less time consuming.

In contrast, in all farms in Belize fertilization is normally used by combining chemical and chicken manure fertilizers, with a higher dependency on chemicals. Dependency on agrochemicals for management is a common practice normally referred to as “use of poison”, however it was impacted by Covid-19 causing a rise in prices (from approximately \$60 Belize Dollars (BZD) to \$80-100 BZD a bag of 45 kg) according to

farmers who took part on the case study. Covid-19 forced them to look for bio-alternatives that could be used together with agrochemicals to achieve the expected yield production at a lower cost, but also consistent with the new approaches of the Belize agricultural extension service towards more sustainable agricultural practices.

“Right now, it is expensive. As it has become expensive we have to use other methods such as chicken manure. Instead of fertilizer we add that one, we plough it and the soil is now composted, and we sow for up to two months because it is hot and all the prices went up right now for the chemicals”

Farm 7HY, San Jose Succotz, Belize, 2021

A systematic review conducted by Mardero et al., (2023) showed that in Central America farmers appeared to be shifting towards more sustainable agricultural practices due to climate change, however results from this study case, as well as participant observation and personal communication with farmers and extension officers, indicate that in Belize farmers management in relation to fertilization and pest control, as well as climate change is still highly dependent on chemical inputs.

Farmers that took part in the case study in Belize and in the survey shared insights around why they continue to use high amounts of chemical fertilizers and came up with similar reasons that included: a) to increase yield productivity (less effort more productivity); b) preference of consumers towards hybrid maize (big maize at low cost) therefore they need to grow crops faster and c) due to climate change and pests.

“I use it because people go by size, size is what they are looking for, if they are looking for a small piece of maize, they say that it will not give them the quantity that the large one gives them, so they look for quality, the size.”

Farm 7HY, San Jose Succotz, Belize 2021

“If there is organic produce, they do not want to buy it because there is enough of the chemical (managed), they are not looking at the chemicals, they are looking at the cheapest one there is. The people here don't want to pay three dollars, they want to pay a dollar, but the three dollars cost is because you are taking care of it (organic). They don't care if it's not chemical, they're going to look for the cheapest one here in Belize that's right, I don't know how it is in other countries. In the United States, there I realized that quality has a good price, there people don't look if it's expensive, they go they want to eat that way (organic), but not here in Belize, in Belize we don't have that system yet. We started it but it didn't work. We started it with the Maya Green Flowers group, we made the compost, we cleaned it by hand, we made the poison (fertilizer) with soap,

epazote, onion. Yes, it turned out well, but when we went to the market, there is a lot and we are selling at a high price, ... from there it discouraged people. It takes time to do it and for it to come like that, even if you mark that it's organic in the back, it won't sell because there's a lot of product."

Farm 5HY, San Antonio, September 2021

"Right now we have a problem, but before it rained more often, now as nature stops, the water stops, the plants do not want to grow, sometimes they die, and what lives takes time and we have to add fertilizer."

Anonymous Farmer , San Antonio, September 2021.

"Now we have to use fertilizers, not like before. Before the lands were virgin, they were fertile. Today the soils are already tired. It is not like before and right now there is a lot of plague."

Anonymous Farmer, Patchakan, September 2021

Another common management strategy reported by farmers in all plots in Mexico and Belize was weed control which was done either by cutting weeds with a machete or applying different types of herbicides. Herbicide is considered as crucial in making *milpa* since all farmers, both in surveys and case studies, agreed that maize can't grow if weeds are left in the plot and that if left then the maize would not complete the growing stage. This shared argument also illustrated the local human capital of farmers about soil functionality and knowledge in relation to weed management and productivity.

Documenting management strategies allowed better understanding of the state of the local environment and how farmers perceive this environment and what has shaped their perceptions and knowledge of soil. This contributed to the discussion of De Souza et al. (2016, p. 9) on how "farmer perception of soil quality has a direct relationship to their personal experience and the local history of land use associated with specific crops and production systems that altered the landscape over time".

Addressing what influences management when completing soil characterisation is essential in systems like *milpa*, especially given the role of knowledge systems in this management; but also, on the high dependency on programmes that use modern globalised knowledge to deal with land management. This was more evident in the case of Belize given their involvement with the extension service. Slegers (2008, p.2017), argues that "programs still depart from the productivity-reducing problems identified and perceived by scientists" rather than focusing on farmers own perception of their

environment and how they behave and make decisions and respond to their local environment (Celio et al., 2014). Since this has been a common practice in research where soil characterisation is determined by scientific methods this study focused instead on integrating approaches for soil characterisation by considering the use of both indigenous and scientific knowledge.

5.3 The use of knowledge systems in soil characterization.

5.3.1. Description and classification of soils using Maya indigenous systems.

The Yucatan Peninsula is characterized for having diverse micro topographical conditions and consequently a wide range of morphological patterns (Bautista-Zuniga et al., 2003; Borges-Gomez et al., 2005). This diversity translates into specific edaphic characteristics that have been the subject of multiple scientific characterizations but are also considered within a Maya traditional classification system and therefore widely used by farmers to decide which crops to grow (Estrada-Medina et al., 2013). Duch (2005, p. 34), referred to the Mayan soil classifications as “part of a broad cultural legacy that endures as part of the everyday speech of rural Yucatecan society...the currently edaphic Mayan terminology continues to be a basic empiric reference for decision-making about the use and agricultural management of soils...decisions that have been historically successful to support the biological and cultural reproduction of this broad social conglomerate”.

5.3.1.1 Indigenous characterization of soils used by farmers

In soil characterizations done previously for the Yucatan state, colour has been a distinctive property indicating that dark (*Box'luum*) and red (*K'ankab*) *leptosols* are dominant soils in the region (Bautista-Zuniga et al., 2003; Estrada-Marina et al., 2013). Osunade (1992, p. 185) argued that “soil colour is perhaps the most conspicuous soil property perceptible to small farmers and it is by direct visual observation in the field”. Farmers both in Yucatan and Belize identified soils based on colour, either naming it as dark (*Box'luum*) or red (*K'ankab*). However, when asked to provide a traditional characterisation of the soil in their plot this was done based not only on soil colour, but also by mentioning Maya classification name, topographic position, properties when wet and dry (texture) and adjacent soils familiar to them either cultivated or non-cultivated (Table 5.2).

Table 6.2. Indigenous knowledge of soils provided by Maya farmers in each of the six different communities in Yucatan (Y) and Belize (B) (Adapted from Estrada-Marina et al. 2013)

Farm ID and Location	Soil colour	Maya Classification	Topographic Position	Description	Other soils identified by farmer
Farm1-HST Oxkintok (Y)	Dark	Box lu'um	Mound (Base)	If dry, the soil feels like dust. If wet, is sticky but dries out quickly, is not like the ak'alche (swampy area) that takes up to two months to dry out.	K'ankab Ek lu'um
Farm 2-LM Oxkintok (Y)	Red	K'ankab	Flat	Not provided.	Box lu'um
Farm 3-LNXY Tzucacab (Y)	Red	Chak'kankab	Flat	If dry, this soil is hard and becomes dusty. Is not very good to plant when dry because you need to dig so you can find humidity. If wet, this soil is very good to plant because soft and manageable and any seed germinates quickly.	Box lu'um Yaxx kon Ich tunich
Farm 4-LGR Xoy (Y)	Red	Chak'kankab	Flat	If dry, is hard. If compacted it forms cracks but inside it looks dusty. If wet, is soft, but not sticky.	Box lu'um
Farm 5-HY San Antonio (B)	Dark	Box lu'um	Mound	If dry, Like dust, like sand. If wet, is not sticky. Is soft when you pass with your boots, but it doesn't get stuck, it is easily removed from boots.	NA
Farm 6-LY San Antonio (B)	Dark	Xkaat Luum/ Shkaat Luum	Mound	If dry, it only dries out from the surface, it looks like cement and cracks but underneath at 2 inches is still wet. It gets flooded because has a lot of humidity. If wet, is sticky and clayey and it takes time to dry, it floods.	Box pus lu'um Sak pus lu'um
Farm 7-HY San Jose Succotz (B)	Dark	Ek' lu'um	Mound	If dry, it cracks everywhere. If wet, you can't plant because maize doesn't germinate.	White soil Yellow soil
Farm 8-HL Patchakan (B)	Red	Xcaan Lu'um	Flat	If dry, it looks red brown and soil feels quite loose, with small stones in some parts If wet the colour is bright red and is clayey.	K'an Kab Akal che

The use of Maya terms like “*luum*”, whose translation would be similar to the word soil, as well as the term “*kab*”, which is used to describe specific soil properties e.g. *sahkab* (white soil) are concepts that for Garcia-Quintanilla (2000, p. 283) “go beyond the occidental meaning of soil as life supporter” and “they are unique ways of recognising elements that are part of the monte”. Considering the above arguments, therefore, for Maya farmers using specific terminology is an expression of the territories they inhabit and the diversity of these territories. In using a specific localized classification, farmers are also illustrating the local human capital of soil reflected in knowledge that has passed through generations. This aligns with De Souza et al.’s (2016, p.6) argument that “soil properties perceived by farmers are based on observation and life experience over time, which is accumulatively transmitted over generations”.

Within the eight studied plots, six different types of soil were recognised by farmers based on the Maya classification: *Box lu'um* (Farm 1 and 5), *K'ankab* (Farm 2) *Chak' K'ankab* (Farm 3 and 4), *Xkaat Luum* (Farm 6), *Ek' lu'um* (Farm 7) and *Xcaan Lu'um* (Farm 8). *Box lu'um*, *Xkaat Luum*, and *Ek' lu'um* were identified as dark soils whereas *K'ankab*, *Chak'K'ankab* and *Xcaan Lu'um* as red soils (Table 2). Two of the soil names given by farmers in Belize in Farm 6-*Xkaat Luum* and Farm 8-*Xcaan Lu'um* were not found in past characterisations. *K'ankab* and *Chak'Kankab* were found to be classified as different types of soils by Estrada-Marina et al. (2013) given the colour characteristics (*K'ankab* light red and *Chak'k'ankab* darker red).

Heterogeneity of soils in Yucatan (Mexico) has been well documented, and in order to examine this at a microscale, farmers were also asked to identify other types of soil present in other plots owned either adjacent or nearby the sampled plots in cultivated or forest/non-cultivated areas. In total nine different types of soil were recognised by farmers with *Box'luum* and *K'ankab/Chak' k'ankab* the predominant types recorded which aligned with the work of Bautista-Zuniga et al. (2003) and Estrada-Marina et al. (2013).

In general, results from this research showed that farmers in both Yucatan and Belize were able to identify at least two different types of soil; however, some differences were observed between young farmers in Yucatan and Belize when doing the classification. In Yucatan both younger and older farmers were able to name different types of soils using the Maya Classification, however, in the case of Belize younger farmers had difficulties

naming them and consultation was done with older family members (mainly the father) to obtain the Maya name.

In identifying and characterising soils, it was noted during participant observation that use of Maya language plays a crucial role. In Mexico, Maya language is used more frequently across both younger and older farmers both written and spoken, however in Belize, the use of Maya language was limited to older farmers and for the most part only spoken. Younger farmers in Belize recognised finding it difficult to converse in Maya, but were familiar with specific terms. This could explain why in some case studies (e.g. Farms 6 and 8) soil nomenclature appeared not to have been written down previously, as the names provided were associated mostly with how they pronounced words or terms. When reviewing soil classification in Belize, guided by the properties provided by farmers and relating the terms to previous scientific soil classifications done in the country it was possible to identify which soil type they were referring to.

Descriptions using specific Maya terms have social implications related to the connection to the “*monte*” for Garcia-Quintanilla (2013), but also an “evidence of destruction of the *monte* and of the *milpa* as culture”. Difficulties in using Maya classification amongst farmers in Belize could be an indirect reflection of the changes in perceptions around the *monte* and in the *milpa* system (Chapter 4).

Documentation of indigenous soil knowledge provided evidence of the high cultural importance that environmental elements continue to have for the Mayan people, as is the case with other indigenous groups in relation with their local environment (Ford et al., 2020). It also provided evidence of farmers extensive knowledge of soil properties and characteristics and the priority given, not only to these properties, but the importance of using their own nomenclature as it assigns and portrays different meanings from modern scientific approaches. Duch (2005, p. 65) contributes to this by stating that “what would be in Spanish a notion of land in its broadest sense, in the Mayan language there is a whole series of specific words, ...some of which also apply to give a name to the type of soil that is located within the limits of local environmental areas, which regularly lends itself to confusion in the interpretations of the scientist regarding the edaphic perception of the farmers” .

Soil is a crucial part of the *monte* and of the territory Maya peoples inhabit, and therefore is an element highly interconnected to many other different place-based elements that

play a role in cultural identity and community resilience to environmental change (Ford et al., 2020). It is also an element that can indirectly provide evidence of the decrease and disconnection in the transmission and use of the Maya language and knowledge in Belize compared to Mexico (see Chapter 4; Section 4.3) and that can be indirectly modifying the local human capital of soils in *milpa* systems.

A special attribute that can also be influencing local human capital of soils in the *milpa* system could be associated with the soil classification surveys available in each of the countries. Belize soil classification is very limited compared to Mexico. The most recent classification of soils in Belize was by Baillie (1993). Before that, King et al. (1986, 1989, 1992) completed a soil classification for Belize, guided by land regions or land systems, and soils were classified mainly based of physiographic characteristics. None of the classifications available for Belize consider the use of Maya terminology in contrast to those available in Mexico (Bautista & Zinck, 2010; Estrada-Medina et al., 2013a). This also indirectly provides evidence of a dominant power-knowledge relation that has historically dismissed indigenous knowledge of local inhabitants. In the case of Maya Yucatec people in Belize, this is most likely rooted in post-colonial practices during the 19th century when Maya people were forced into a colonial social structure that severed their natural relationship with the forest, to later incorporate them into agricultural practices and labour work aimed to increase and capitalize crops. This changed the cultural ecology and social structure of Maya people and their indigenous knowledge (Bolland, 2003). It is no surprise then that people in Belize rely mainly on oral transmission for learning about indigenous soil classification or the remains of such knowledge. The country also lacks resources that can integrate cultural ecology of soils with modern soil classification, nor there are financial resources for doing this.

The rupture of transmission around indigenous knowledge systems as discussed in Chapter 4, has implications for the ways the environment in Belize is conceptualized, in this case soils (local human capital) and therefore in the way it is prioritised for decision making related to productivity. In contrast Maya farmers in Mexico continue to prioritise a way of life rooted in elements from the environment, such as soil, and priority is given to take care of such elements to guarantee the continuation of local livelihoods, self-subsistence and cultural identity. In this sense Duch (2005, p. 66) suggests then that “the Mayan nomenclature of soils be understood as a symbolic way of giving unity to the

empirical perception of the regional edaphic diversity, which has been shaped by the Mayan farmers as an essential piece of their process of cultural evolution”.

5.3.1.2 Topographic position

Farmers’ perceptions of topographic position are based on a visual representation of geomorphological features and surrounding elements rather than guided by scientific assessments. This way of knowing continues to be part of the connection of Maya people with the different spaces of their territory, across ecological, socioeconomic and spiritual dimensions (Riu-Bosoms et al., 2015). Maps from the early post-colonial period in Mexico showed that special features in the *monte* were the way of delimiting the territory and a way of ancient milperos to record where one *milpa* started and another finished. Ancient limits of territory were referred as *rutas* (routes e.g. Ruta Puuc) which included cenotes, watering holes, caves, *muuls* (archeological sites) and showed the limits of the people’s properties. For ancient and modern Maya peoples each of these features also have several different spirits that protect these spaces and where many of the stories of Maya collective life have their origin.

However, with the European tradition of representing land holding, Maya people were forced into a re-organization of their territory and required to use linear limits. By imposing these ways of viewing land, Europeans wanted to eliminate the scattered indigenous settlement pattern to reduce it to spaces where colonial authorities could have more control of the Maya indigenous population (Solari, 2010). As a result, Maya peoples own way of representing their territories and perceiving their surroundings changed, or were adapted, but there are some that are still used by modern milperos. Modifying how local people perceive their landscape from which they depend to survive (Riu-Bosoms et al., 2015) represents a big challenge for local classification systems, such as the Maya soil classification, given that compared to scientific ones which consider selected elements such as plants species, soil types or hydrological features (Campos et al., 2014), Maya indigenous classifications also consider the distributions of life forms and spaces that help support livelihoods and are based on social, cultural and spiritual importance (Campos et al., 2014; Khromer, 2010).

Within this study, farmers in Mexico and Belize identified two different topographic positions associated with soil characteristics: Mounds and Flat/Plain Landscapes, but during participant observation and informal conversations Maya farmers often kept using

Maya terms to refer to certain topographic areas within their *milpas* (e.g. *muuls* and *cenotes*). Specific soil characteristics based on the topographic positions identified by farmers were compared to those assigned by scientific analysis of soil types (section 5.3) to see if there were any disparities. In both cases the conclusion is similar in that topographic position impacts soil characteristics and functionality recognising the variety of soils and influencing farmer's decision making about which crops to plant in specific type of soils. Within this research, farmers perceptions of landscape in relation to topography aligned with scientific descriptions of elevation based on measurements of altitude.

5.4 Physicochemical characteristics of soils in *milpas* in Mexico and Belize determined by scientific analysis.

A descriptive process of management strategies and soil characterisation using indigenous knowledge contributed to a better interpretation of the soil physicochemical analysis conducted using scientific methods. Measuring soil properties was not the main purpose of this study, however, a basic assessment of physicochemical properties (See Chapter 3; Section 3.8.2.1) was used to help understand the current quality of different type of soils present in *milpa* managed under different conditions. This was of interest for the research given that although traditional characterisation (qualitative description) is frequently used by farmers, scientific/agronomic soil assessments are not as commonly practiced as expected in either country, therefore farmers do not relate lower yields with soil quality or soil fertility, and in most cases properties are overlooked compared to other environmental conditions such as weather (e.g. rainfall variability or drought; Östberg, 1995).

5.4.1. Soil colour

Soil colours can be classified as red, yellow, brown, black, white and grey and range across 175 different colours classification based on the Munsell Colour chart (Osunade, 1992). The diversity of colour in soils is the result of soil composition in relation to three main elements: humus (black), hydroxides of iron (red) and silicic acid, kaolinite and calcium carbonate (white; Ibáñez-Asensio et al., 2013). Depending on other components present in soils, such as certain nutrients like nitrogen or phosphorus, colours can vary. Due to this and the familiarity of farmers with soil colour and soil properties important remarks were documented around this property.

Most of the farmers visual classification recognize and use two main dominant colours: dark (which can include shades of black, dark brown and brown) and red (see 5.3.1 and Table 11). Interesting perceptions were recorded regarding the dominant spectral colour. Most of the farmers (seven out of eight) recognised and classified their soil in colour gradients which would be like those in the Munsell Chart colour. Farmers from Farm 3 and 8 respectively identified the soil colour of their plot as red which when compared to the Munsell Chart colour the soils are classified as brown with reddish hues (dark reddish brown), however farmers highlighted that this colour is variable depending if the soil is dry or wet or based on the depth of the soil or when exposed to the light of the sun. This characterisation highlighted how and what variables farmers use to identify soils and how their characterisation is mostly done around the dominant colour (the hues) based on when soil is dry in this case the red colour (the reddish hues); but also highlighted their ability to identify what in the scientific method would be the chroma and the values. This perception of soil colour is the result of years of observations of their own environment (Park, 1999) and in this case of soils colours that are familiar to them.

In general, farmers used the distinctive change in soil colour to classify their own either as dark or red, but with a self-awareness of the colour variability under different conditions and which has been one of the baselines of the Maya Soil classification. Table 5.3 and Figure 5.1 shows the colour diversity among studied plots using both farmers visual classification and Munsell chart colour.

Table 6.3. Soil colour determination by farmers compared to Munsell Colour system

Farm ID	Farmer's Visual Classification	Munsell Chart Classification	Munsell Colour
Farm1-HST	Dark	2.5 YR/2.5/3	Dark Reddish Brown
Farm 2-LM	Red	10R/ 3/ 3	Dusky Red
Farm 3-LNXY	Red	5YR/ 2.5/2	Dark Reddish Brown
Farm 4-LGR	Red	10R/2.5/2	Very Dusky Red
Farm 5-HY	Dark	10YR/2 /2	Very Dark Brown
Farm 6-LY	Dark	10YR/ 2/1	Black
Farm 7-HY	Dark	10YR/ 2/ 2	Very Dark Brown
Farm 8-HL	Red	10 R/2.5/ 1	Dark Reddish Brown

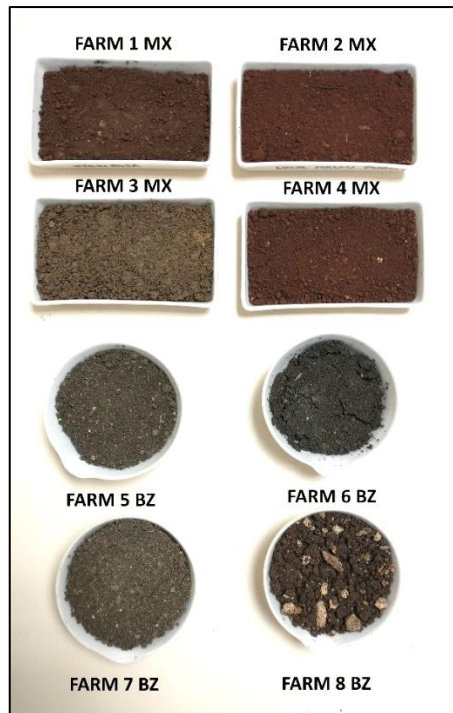


Figure 6.1 Visual comparison of soil colour amongst eight different *milpa* plots in Mexico and Belize.

5.4.2. Soil physicochemical properties

Analysis of physical and chemical properties of the soils collected in Mexico and Belize (see Chapter 3, Section 3.8.2.1) included particle size distribution, textural class, colour, organic matter, pH and nutrient availability (Nitrogen Nitrate-NO₃-N, Phosphate-P and Potassium-K; Table 5.4). From each of the soil attributes descriptive statistics showed that pH is the characteristic that presented the lowest variability/heterogeneity amongst the studied plots (pH 6.5-7.5), with just a 6.6% of coefficient of variation (CV). In contrast to this, the properties potassium, phosphate, and particle size distribution (sand, silt and clay) showed high variability/heterogeneity amongst the studied plots, with a coefficient of variation above 40% (Table 5.5). From each of the soil attributes descriptive statistics were also run per country to identify potential differences and similarities (Table 5.6).

In order to identify potential changes in soil quality in response to changes in land use, in six (Farm 1, 3, 4, 5, 7 and 8) out of the eight monitored plots an assessment of physicochemical properties (% organic matter, pH and nutrient availability) from adjacent forested/uncultivated areas was also completed and compared with those from cultivated plots (Table 5.7).

Table 6.4. Summary of physical and chemical characteristics of soils in Maya *milpas* in Yucatan (Y) and Belize (B) (see Chapter 3 Methods)

Farm ID	Munsell Colour	Munsell Classification	Textural class	Particle size distribution			OM%	pH	NO ₃ -N (ppm)	P (ppm)	K (ppm)
				Sand %	Silt %	Clay %					
Farm1-HST	Dark Reddish Brown	2.5 YR/2.5/3	Sandy Loam	50.3	36.0	13.7	12.8	7.5	256.8	18	60
Farm 2-LM	Dusky Red	10R/ 3/ 3	Sandy Loam	69.6	23.1	7.3	13.8	6.5	239.2	19	115
Farm 3-LNXY	Dark Reddish Brown	5YR/ 2.5/2	Sandy Loam	52.8	37.7	9.5	15.0	6.5	226.8	1	115
Farm 4-LGR	Very Dusky Red	10R/2.5/2	Sandy Loam	68.3	24.6	7.1	14.6	7.5	267.6	3	120
Farm 5-HY	Very Dark Brown	10YR/2 /2	Clay	26.7	37.6	35.7	10.0	6.5	411.20	13	70
Farm 6-LY	Black	10YR/ 2/1	Clay	23.3	31.2	45.5	14.1	7.0	363.20	10	55
Farm 7-HY	Very Dark Brown	10YR/ 2/ 2	Silty Clay	6.1	54.7	39.2	7.3	7.0	235.40	14	30
Farm 8-HL	Dark Reddish Brown	10 R/2.5/ 1	Silty Clay Loam	3.6	72.8	23.6	12.7	7.5	359.60	6	40

Table 6.5. Descriptive statistics of soil attributes in eight cultivated plots in Yucatan and Belize.

		Organic Matter %	pH	Nitrate Nitrogen (NO ₃ -N) ppm	Phosphate (P) ppm	Potassium (K) ppm	Sand %	Silt %	Clay %
N	Valid	8	8	8	8	8	8	8	8
	Missing	0	0	0	0	0	0	0	0
Mean		12.54	7.0	294.98	10.50	75.63	37.59	39.71	22.70
Std. Error of Mean		0.93	0.16	25.30	2.37	12.76	9.29	5.85	5.51
Std. Deviation		2.63	0.46	71.57	6.70	36.10	26.27	16.56	15.57
CV (%)**		21 (H)	6.6 (L)	24.3 (H)	63.8 (VH)	47.7 (VH)	69.9 (VH)	41.7 (VH)	68.6 (VH)
Variance		6.90	0.21	5121.980*	44.86	1303.13	690.05	274.08	242.52
Range		7.70	1.0	184.40	18	90	66.00	49.70	38.40
Minimum		7.30	6.5	226.80	1	30	3.60	23.10	7.10
Maximum		15.00	7.5	411.20	19	120	69.60	72.80	45.50

*High variances are the result of limited samples available for the analysis when processed by software.

** (VH)= Very High variability (H)= High variability (L)=Low variability

Table 6.6. Descriptive statistics of soil attributes across all samples per country (MX=Mexico; BZ=Belize)

Country			Organic Matter %	pH	NO ₃ -N ppm	Phosphate (P) ppm	Potassium (K) ppm	Sand %	Silt %	Clay %
MX	N	Valid	4	4	4	4	4	4	4	4
		Missing	0	0	0	0	0	0	0	0
	Mean		14.05	7.0	247.60	10.25	102.50	60.25	30.35	9.40
	Std. Error of Mean		0.49	0.29	9.07	4.78	14.22	5.06	3.78	1.53
	Std. Deviation		0.97	0.58	18.15	9.57	28.43	10.11	7.56	3.07
	Variance*		0.94	0.33	329.28	91.58	808.33	102.24	57.19	9.40
	Range		2.20	1.00	40.80	18.00	60.00	19.30	14.60	6.60
	Minimum		12.80	6.50	226.80	1.00	60.00	50.30	23.10	7.10
	Maximum		15.00	7.50	267.60	19.00	120.00	69.60	37.70	13.70
BZ	N	Valid	4	4	4	4	4	4	4	4
		Missing	0	0	0	0	0	0	0	0
	Mean		11.03	7.0	342.35	10.75	48.75	14.93	49.08	36.00
	Std. Error of Mean		1.51	0.20	37.54	1.80	8.75	5.88	9.34	4.60
	Std. Deviation		3.01	0.41	75.08	3.59	17.50	11.76	18.67	9.21
	Variance*		9.06	0.17	5636.97	12.92	306.25	138.31	348.57	84.78
	Range		6.80	1.00	175.80	8.00	40.00	23.10	41.60	21.90
	Minimum		7.30	6.5	235.40	6.00	30.00	3.60	31.20	23.60
	Maximum		14.10	7.5	411.20	14.00	70.00	26.70	72.80	45.50

*High variances are the result of limited samples available for the analysis when processed by software.

Table 6.7. Descriptive statistics of soil attributes in cultivated plots and adjacent forest /non-cultivated areas in six plots in Yucatan and Belize

		Organic Matter % (C)	Organic Matter % (F/NC)	pH (C)	pH (F/NC)	NO3-N Ppm (C)	NO3-N ppm (F/NC)	Phosphate (P) ppm (C)	Phosphate (P) ppm (F/NC)	Potassium (K) ppm (C)	Potassium (K) ppm (F/NC)
N	Valid	6	6	6	6	6	6	6	6	6	6
	Missing	0	0	0	0	0	0	0	0	0	0
	Mean	12.07	17.48	7.08	6.58	292.90	313.02	9.17	11.67	72.50	85.00
	Std. Error of Mean	1.20	1.43	0.20	0.34	30.58	86.48	2.77	5.60	15.37	4.28
	Std. Deviation	2.93	3.51	0.49	0.83	74.92	211.83	6.79	13.71	37.65	10.49
	Variance*	8.59	12.31	0.24	0.69	5612.51	44872.75	46.17	187.87	1417.50	110.00
	Range	7.70	9.90	1.00	2.40	184.40	579.30	17.00	37.00	90.00	25.00
	Minimum	7.30	12.40	6.50	5.00	226.80	44.70	1.00	1.00	30.00	75.00
	Maximum	15.00	22.30	7.50	7.40	411.20	624.00	18.00	38.00	120.00	100.00

C=Cultivated F/NC=Forest/Non-Cultivated

*High variances are the result of limited samples available for the analysis when processed by software.

5.4.3. Differences between soil colour in relation to physicochemical properties

Given that soil colour is a characteristic that farmers widely used for decision-making in relation to what to plant, comparisons between red and dark soils according to the Munsell classification was done for organic matter (OM%), Potassium, Phosphate and Nitrate-Nitrogen (Table 5.8) and differences were examined to see if they were statistically significant.

The results of the descriptive statistics show that the red soils had higher values for the variable OM% ($M = 13.78$, $SD = 1.04$) than the Dark soils ($M = 10.47$, $SD = 3.42$). A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between Red and Dark with respect to the variable OM% was not statistically significant, $t(6) = 2.11$, $p = .079$, 95% confidence interval $[-0.53, 7.16]$. In relation to macronutrients, the descriptive statistics show that the Red soils had higher values for the dependent variable Potassium (K) ($M = 90$, $SD = 37.25$) than the Dark soils ($M = 51.67$, $SD = 20.21$). A two-tailed t-test for independent samples (equal variances assumed) showed that this difference was not statistically significant, $t(6) = 1.61$, $p = .158$, 95% confidence interval $[-19.88, 96.55]$.

Contrary to this the Red soils had lower values for the variable Phosphate (P) ($M = 9.4$, $SD = 8.5$) than the Dark soils ($M = 12.33$, $SD = 2.08$). A two-tailed t-test for independent samples (equal variances not assumed) showed that the difference was not statistically significant, $t(4.74) = -0.74$, $p = .497$, 95% confidence interval $[-13.4, 7.53]$. The Red soils also showed lower values for the variable Nitrate Nitrogen $\text{NO}_3\text{-N}$ ($M = 270$, $SD = 52.5$) than the Dark soils ($M = 336.6$, $SD = 90.87$). A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between Red and Dark with respect to the dependent variable Nitrate Nitrogen ($\text{NO}_3\text{-N}$) was not statistically significant, $t(6) = -1.35$, $p = .227$, 95% confidence interval $[-187.66, 54.46]$.

Table 6.8. Descriptive statistics of soil properties in relation to soil colour.

Property	Soil colour	n	Mean	Std. Deviation	Std. Error Mean
OM%	Red	5	13.78	1.04	0.46
	Dark	3	10.47	3.42	1.98
Potassium (K) ppm	Red	5	90	37.25	16.66
	Dark	3	51.67	20.21	11.67
Phosphate (P) ppm	Red	5	9.4	8.5	3.8
	Dark	3	12.33	2.08	1.2
Nitrate-Nitrogen (NO ₃ -N) ppm	Red	5	270	52.5	23.48
	Dark	3	336.6	90.87	52.46

5.4.4. Particle Size Distribution

Soils are composed of different types of material from large to small particles and particularly in the *milpa* system the size of this material helps determine the physical and chemical properties of the soil. Results from the Laser Diffraction Method to determine particle size distribution and soil texture (see Chapter 3, Section 7.2.1) showed that the studied plots across Mexico and Belize fall within four different types of soil texture: Sandy loam, silty clay, silty clay loam and clay (Table 5.9).

All four studied plots across three communities in Yucatan, Mexico showed a sandy loam soil texture. Plots in Belize showed three different textural classes across the studied communities. In upland areas like San Antonio, the textural class in Farms 5 and 6 was clay. Farm 7 in San Jose Succotz/Calla Creek showed a silty clay structure and Farm 8 in Patchakan a silty clay loam.

Table 6.9. Textural group obtained by laser particle size analysis for each of the eight plots in Yucatan (Y) and Belize (B); descriptions provided by farmers and scientific descriptions in relation to soil type and properties.

Farmer ID	Textural class	Description by Farmers	Description by Literature (Scientific descriptions)
Farm1-HST (Y)	Sandy Loam	If dry, the soil feels like dust. If wet, is sticky but dries out quickly, is not like the <i>ak'alche</i> (swampy area) that takes up to two months to dry out.	“Material has 7 to less than 20 percent clay and more than 52 percent sand, and the percentage of silt plus twice the percentage of clay is 30 or more; OR material has less than 7 percent clay and less than 50 percent silt, and the percentage of silt plus twice the percentage of clay is 30 or more” (USDA, 2018). Sand grains can be felt and are visible (gritty feel). It often dries fast, disintegrates easily and have a quick draining. However, they have reduced water-holding capacity and nutrient deficient specifically micronutrients as a result, they require more frequent irrigation and fertilization than those with higher clay concentrations. They are also prone to erosion if not managed properly. (Parihar et al. 2016; Rowell, 1994). When dry, it will form a cast that will instantly fall apart; but when moist it will form a cast that will hold without breaking. It stains fingers. When placed in water it turns the water cloudy (USDA, 2018)
Farm 2-LM (Y)	Sandy Loam	Not provided	
Farm 3-LNXY (Y)	Sandy Loam	If dry, this soil is hard and becomes dusty. Is not very good to plant when dry because you need to dig so you can find humidity. If wet, this soil is very good to plant because soft and manageable and any seed germinates quickly	
Farm 4-LGR (Y)	Sandy Loam	If dry, is hard. If compacted it forms cracks but inside it looks dusty. If wet, is soft, but not sticky.	
Farm 5-HY (B)	Clay	If dry: Like dust, like sand.	“Material has 40 percent or more clay, 45 percent or less sand, and less than 40 percent

		If wet, is not sticky. Is soft when you pass with your boots, but it doesn't get stuck, it is easily removed from boots.	silt. Clay soils are sticky in some areas and not sticky in others. It will feel neither gritty nor smooth" (USDA, 2018). Clay soils are sticky in some areas and not sticky in others. When moist is both sticky and plastic. Produces a high sheen when rubbed with the thumbnail and forms a strong ball resistant to breaking (USDA, 2018).
Farm 6-LY (B)	Clay	If dry, it only dries out from the surface, it looks like cement and cracks but underneath at 2 inches is still wet. It gets flooded because has a lot of humidity If wet, is sticky and clayey and it takes time to dry, it floods.	The main characteristic of clay soil is good retention of water; they can hold more water than other soils however they have poor drainage of excess water. They are often sticky and easy puddled. They are deficient in phosphates but rich in potassium. The structure of this soil is very sensitive to changes in climate conditions as when they are wet, they tend to swell and when dry they tend to shrink (Rowell, 1994).
Farm 7-HY (B)	Silty Clay	If dry, it cracks everywhere. If wet, you can't plant because maize doesn't germinate. Deep soil is yellow and sometimes white.	"Material has 40 percent or more clay and 40 percent or more silt. Is both plastic and sticky when moist and lacks any gritty feeling, it feels very smooth. Dry it is extremely hard and it feels quite floury when crushed. It is very sticky and very plastic when moist and it shows a good fingerprint; it forms a cast that can bear much handling, it clouds water and stains fingers" (USDA, 2018).
Farm 8-HL (B)	Silty Clay Loam	If dry, it looks red brown and soil feels quite loose, with little stone in some parts. If wet the colour is bright red and is clayey	"Material has 27 to less than 40 percent clay and 20 percent or less sand. Is sticky when moist" (USDA, 2018)

Descriptive statistics in relation to the particle size distribution were obtained for the eight plots showing that within all the plots silt had higher values ($M = 39.71$, $SD = 16.56$) than sand ($M=37.59\%$, $SD=26.27$) and clay ($M=22.70$, $SD= 15.57$; Table 5.10).

Table 6.10. Descriptive statistics of particle size distribution in eight plots in Yucatan and Belize

		Sand %	Silt %	Clay %
N	Valid	8	8	8
	Missing	0	0	0
Mean		37.59	39.71	22.70
Std. Error of Mean		9.29	5.85	5.51
Std. Deviation		26.27	16.56	15.57
Variance*		690.05	274.08	242.52
Range		66.00	49.70	38.40
Minimum		3.60	23.10	7.10
Maximum		69.60	72.80	45.50

*High variances are the result of limited samples available for the analysis when processed by software.

When analysed per country descriptive statistics showed that in Mexico, the particle size values for sand showed the highest levels of distribution ($M= 60.25\%$, $SD= 10.11$) followed by Silt ($M= 30.35\%$, $SD= 7.56$); while clay showed the lower levels ($M= 9.40\%$, $SD= 3.07$). In contrast Belize, showed that Silt has the higher levels of distribution ($M=49.08\%$, $SD=18.67$) followed by Clay ($M=36\%$, $SD=9.21$); while sand showed the lower levels ($M= 14.93\%$, $SD=11.76$; Table 5.11).

Table 6.11. Descriptive statistics of particle size distribution per country

Country			Sand %	Silt %	Clay %
Mexico	N	Valid	4	4	4
		Missing	0	0	0
	Mean		60.25	30.35	9.40
	Std. Error of Mean		5.06	3.78	1.53
	Std. Deviation		10.11	7.56	3.07
	Variance		102.24	57.19	9.40
	Range		19.30	14.60	6.60
	Minimum		50.30	23.10	7.10
	Maximum		69.60	37.70	13.70
Belize	N	Valid	4	4	4
		Missing	0	0	0
	Mean		14.93	49.08	36.00
	Std. Error of Mean		5.88	9.34	4.60
	Std. Deviation		11.76	18.67	9.21
	Variance*		138.31	348.57	84.78
	Range		23.10	41.60	21.90
	Minimum		3.60	31.20	23.60
	Maximum		26.70	72.80	45.50

*High variances are the result of limited samples available for the analysis when processed by software.

5.4.5. Organic Matter

Soil organic matter is a mixture of residues from living organisms (plants and animals; Rowell 1994). The decomposition of soil organic matter into humus (dark colouring component), is a natural biological process determined by physical environmental conditions and soil organisms, where different components break down and are then released in the form of energy, carbon dioxide (CO₂) and plant nutrients which can be used by plants. In agricultural soils this process provides crops with nutrients necessary to produce effective yields (FAO 2020).

Organic matter is responsible for several biological, chemical and physical functions in agricultural soils including the following: a) protection from the effect of different weather patterns such as rainfall and sun; b) energy source and nutrient reservoir; c) maintenance and improvement of soil structure; d) minimizing erosion; e) pH regulation and f) water retention (FAO 2020; Rowell and Rowell, 1994) Decomposition and accumulation of soil organic matter are linked processes determined and influenced by

soil properties such as pH, texture, temperature, moisture and biological activities among others, as a result of this, any changes in organic matter will modify this same properties impacting soil functionality (FAO 2020; Julca-Otiniano et al., 2006).

Based on the LOI analysis (see Chapter 3, Section 3.8.2.1) the organic matter content (OM) overall for the eight sampled plots varied from 7.3 to 15 %, with a mean value of 12.54 ± 2.63 (Table 5.12; Figure 5.2) with a coefficient of variation of 21% which shows medium variability in the studied soils.

Table 6.12. Descriptive statistics of % organic matter in eight plots in Yucatan and Belize

Organic Matter		
N	Valid	8
	Missing	0
Mean		12.54
Std. Error of Mean		0.93
Std. Deviation		2.63
Variance		6.90
Range		7.70
Minimum		7.30
Maximum		15.00

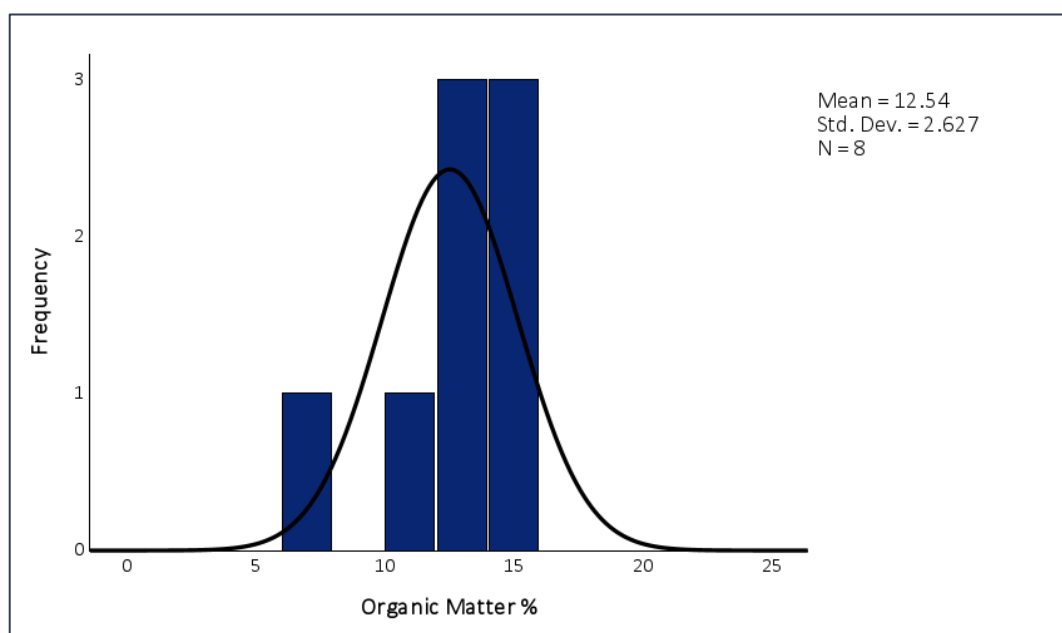


Figure 6.2. Organic matter content (%) of soil sampled in plots from Mexico and Belize.

When compared by country, Mexico showed the highest OM values between 12.8 and 15%, with a mean value of 14.05 ± 0.97 , while Belize showed values between 7.3 and 14.1 %, with a mean value of 11.03 ± 3.01 (Table 5.13).

Table 6.13. Descriptive statistics of % organic matter per country

Organic Matter			
Mexico	N	Valid	4
		Missing	0
	Mean		14.05
	Std. Error of Mean		0.49
	Std. Deviation		0.97
	Variance		0.94
	Range		2.20
	Minimum		12.80
	Maximum		15.00
Belize	N	Valid	4
		Missing	0
	Mean		11.03
	Std. Error of Mean		1.51
	Std. Deviation		3.01
	Variance		9.06
	Range		6.80
	Minimum		7.30
	Maximum		14.10

OM values across all four plots in Mexico were classified as high based on the Norma Oficial Mexicana NOM-2002 standards (Table 5.14). In the case of Belize, since there are no standard/norms for Belize, the Mexican NOM-2002 standards were used for all plots, which indicated that all four plots in this country also contained high levels of OM and these levels are more variable across districts and communities compared to Mexico.

Table 6.14. Reference levels of soil organic matter based on SEMARNAT 2002 (Secretariat of Environment and Natural Resources) for mineral soils (adapted from Ramírez-Silva et al., 2021).

Farm	OM %	Soil Test Reference (NOM-2002)		
		High	Medium	Low
		3.6-6.0	1.6-3.5	0.6-1.5
Farm1-HST	12.8	●		
Farm 2-LM	13.8	●		
Farm 3-LNXY	15.0	●		
Farm 4-LGR	14.6	●		
Farm 5-HY	10.0	●		
Farm 6-LY	14.1	●		
Farm 7-HY	7.3	●		
Farm 8-HL	12.7	●		

In terms of management, across both countries intercropped systems showed the highest levels of OM ($14.05 \pm 0.97\%$), followed by crop rotation ($12.27 \pm 2.08\%$). These two systems have proved to be beneficial to crop yield in similar systems in Africa (Thierfelder, 2012) especially if rotated or if intercropping is done with leguminous crops as in the case of traditional *milpa* practiced in Mexico. In southern Mexico it has been reported that OM in intercropped systems may increase after several years and may be more beneficial in relation to erosion management compared to monocropping (Pierre et al., 2022). Similar results for soil fertility in intercropping and monocropping plots were found in northwest China, although OM did not differ significantly, it did increase in maize/legume intercropping systems after some years (Wang et al., 2014). In general, continuous maize (monocropping) can produce more maize yield but it can bring more challenges to soil in the long term (Thierfelder, 2012) compared to maize/legume intercropping which can help maintain soil fertility (Wang et al., 2014) while minimizing farm expenses and providing similar profits (Yap et al., 2017).

This could explain why farmers decision-making in relation to management in Mexico continues to be more inclined towards an intercropped system and biofertilization especially considering that the main driver for *milpa* management is food security (self-subsistence) as this helps reduce costs and risks around this driver. Water stress, misguided fertilization processes and underlying socioeconomic conditions can however compromise the benefits of this system (Pierre et al., 2022). In contrast farmers in Belize, whose main driver is marketing and finance, the management practice adopted to achieve specific productivity goals is rotation and monocropping which they use together with chemical fertilization. However often this management can have severe impacts in soil

fertility and should be monitored in a regular basis which is not the case for farmers in Belize.

When comparing the OM of cultivated plots and adjacent forested areas the descriptive statistics (Table 5.15) showed that the mean organic matter in six cultivated soils (12.07 ± 2.93 %; Figure 5.3) was lower than organic matter in six adjacent forest/uncultivated soils (17.48 ± 3.51 %; Figure 5.4). A t-test for paired samples showed that this difference was statistically significant, $t(5) = -2.7$, $p = .043$, 95% Confidence interval [-10.58, -0.25].

Table 6.15. Organic matter content in six cultivated plots and adjacent forest/non-cultivated areas in Mexico and Belize. (C=Cultivated F/NC=Forest/Non-Cultivated)

		Organic Matter % (C)	Organic Matter % (F/NC)
N	Valid	6	6
	Missing	0	0
Mean		12.07	17.48
Std. Error of Mean		1.20	1.43
Std. Deviation		2.93	3.51
Variance		8.59	12.31
Range		7.70	9.90
Minimum		7.30	12.40
Maximum		15.00	22.30

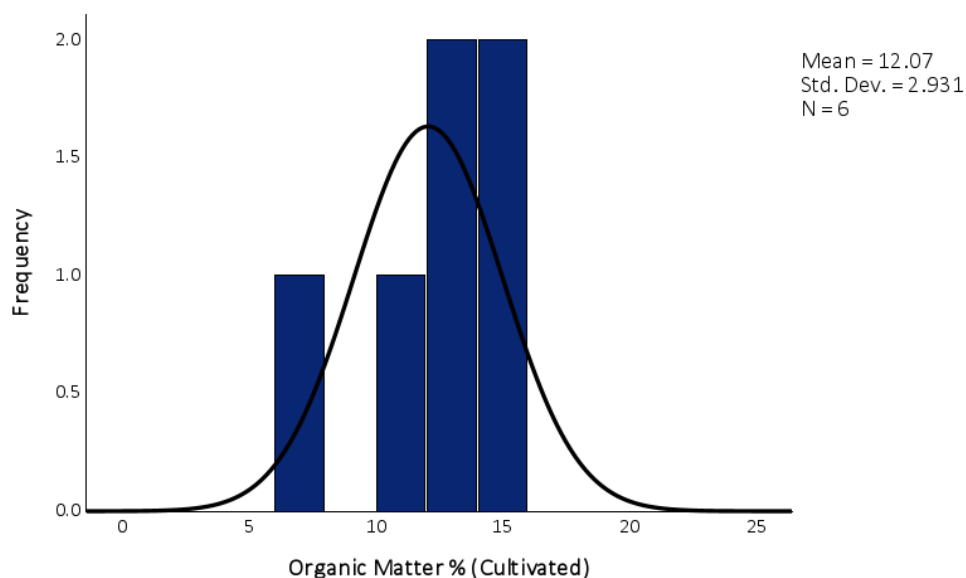


Figure 6.3. Organic matter content (%) of soil sampled in six cultivated plots from Mexico and Belize.

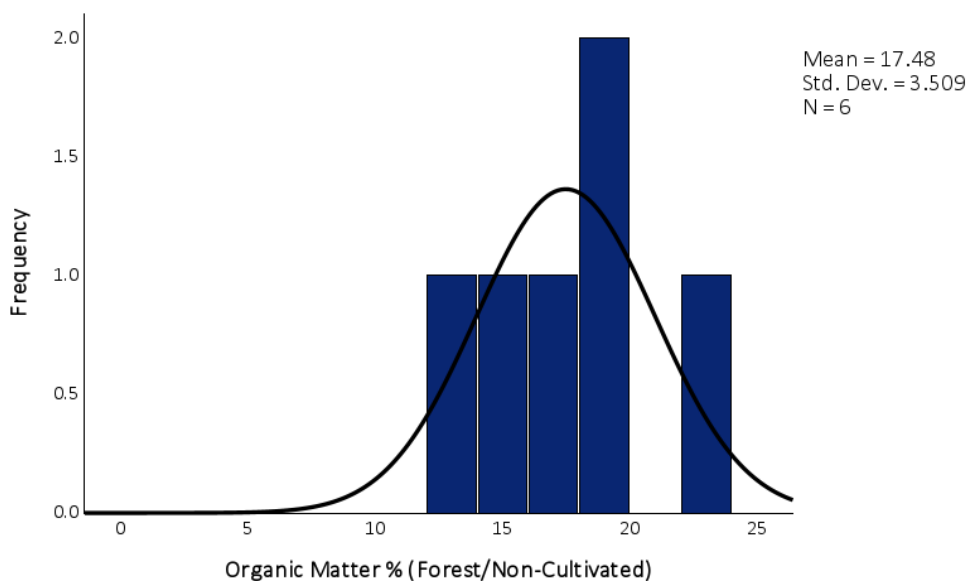


Figure 6.4. Organic matter content (%) of soil sampled in six forest/non-cultivated areas from Mexico and Belize.

When comparing the organic matter content in relation to the type of fertilization (biofertilization, chemical or combined) across all eight plots a one-factor analysis of variance showed that there was no significant difference between the type of fertilization and the variable OM% $F = 4.77$, $p = .069$.

5.4.6 pH in Soil

In relation to soil pH overall, in plots from across Mexico and Belize, values ranged in between 6.5 and 7.5 with a mean value of 7 ± 0.463 (Table 5.16; Figure 5.5).

Table 6.16. Descriptive statistics of pH levels per country

Country	Mean	N	Std. Dev	Std. Error of Mean	Min	Max	Variance	Range
Mexico	7.0	4	0.577	0.289	6.5	7.5	0.333	1
Belize	7.0	4	0.408	0.204	6.5	7.5	0.167	1
Total	7.0	8	0.463	0.164	6.5	7.5	0.214	1

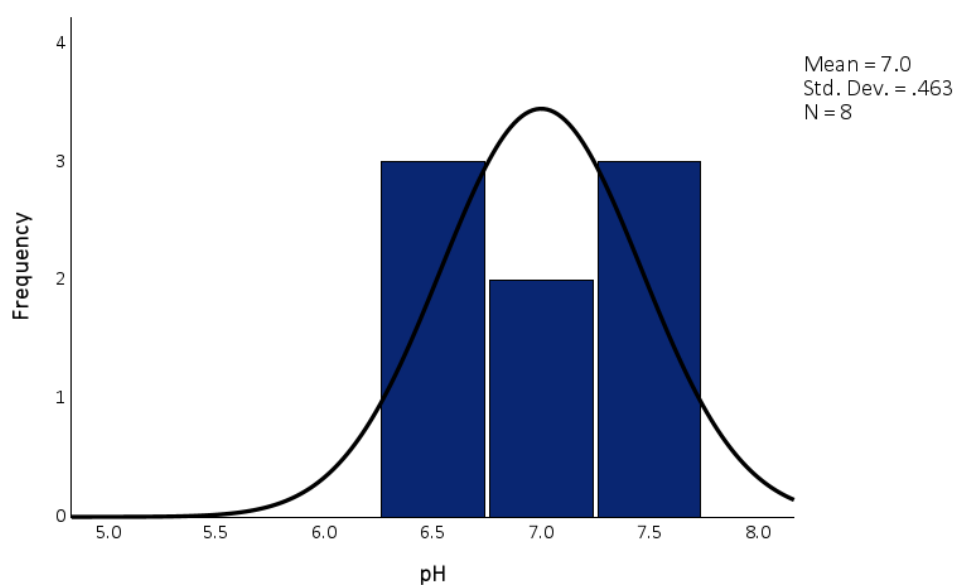


Figure 6.5. pH values of soil sampled in eight plots from Mexico and Belize.

The mean value indicates that the sampled soils fell into a neutral grade of alkalinity according to the SEMARNAT, NOM-2002 limits (Table 5.17).

Table 6.17. Grade of alkalinity indicated by soil pH in eight *milpa* plots sampled in Yucatan (Y) and Belize (B) based on SEMARNAT's (2002) classification.

Farmer ID	Soil pH	Grade
Farm1-HST (Y)	7.5	Mildly alkaline
Farm 2-LM (Y)	6.5	Slightly acidic
Farm 3-LNXY (Y)	6.5	Slightly acidic
Farm 4-LGR (Y)	7.5	Mildly alkaline
Farm 5-HY (B)	6.5	Slightly acidic
Farm 6-LY(B)	7.0	Neutral
Farm 7-HY (B)	7.0	Neutral
Farm 8-HL (B)	7.5	Mildly alkaline

Values obtained fall into the ideal conditions for maize production. Maize crops require a soil pH of between 5.5 and 7.8, however optimal levels lie between 6.0 - 6.5. Soil pH levels outside the normal range, either higher or lower, can compromise the availability of nutrients. A pH below 5.5 can cause issues related to toxicity from nutrients such as aluminium, as well as lack of phosphorus and magnesium. Soil pH levels above 7.0 in calcareous soils or 8.0 in other soils can cause a lack of certain nutrients such as iron, manganese and zinc (ICCA; FAO). Since rainfall can continually add acid to soil and given that samples were taken during the peak of rainy season in both countries (September 2021), future analysis across seasons should be completed to assess changes in such pH conditions. This unfortunately was not possible in this study given the constraints of Covid-19. The results presented however provided a good overview of pH levels within each of the plots given their different management practices.

Previous reports for *milpas* in Yucatan have shown pH values ranged from 6.85 to 7.64 (Ramirez-Silva et al. 2021) and 6.6 to 7.8 (Bautista et al., 2003; 2004) therefore all plots in Mexico fell into normal ranges. Baillie (1993) reported pH values between 5.2-7.9 with a median of 6.4, for soils that fall under the Chacalte suite Xpicilha Subsuite (dark soils; Farm 7/7.0). Soils under the Yaxa Suite, Yalbac Subsuite (dark soils) had values in between 6.0-8.0 with a median of 7.2 (Farm 6/7.0). Soils under the Pembroke Suite and Xaibe (red and brown soils) had values between 6.7-7.6 and median of 7.4 (Farm 8/7.5). In average all pH soils values obtained in plots in Belize fall within the normal ranges previously reported for each of the soil type (Baillie, 1993).

When comparing pH in cultivated soils results showed higher values (7.08 ± 0.49) than the pH in the Forest/Non-cultivated sites 6.58 ± 0.83 . (Table 5.18; Figure 5.6 and Figure 5.7). A t-test for dependent samples showed that this difference was not statistically significant, $t(5) = 1.79$, $p = .133$, 95% Confidence interval $[-0.22, 1.22]$. These results showed a p-value of .133, which is above the specified significance level of 0.05.

Table 6.18. Descriptive Statistics of pH in cultivated and forest/uncultivated soil sampled in six areas in Mexico and Belize in 2021.

N	Valid Missing	pH Cultivated	pH Forest/Non- Cultivated
		6 0	6 0
Mean		7.08	6.58
Std. Error of Mean		0.20	0.34
Std. Deviation		0.49	0.83
Variance		0.24	0.69
Range		1.00	2.40
Minimum		6.50	5.00
Maximum		7.50	7.40

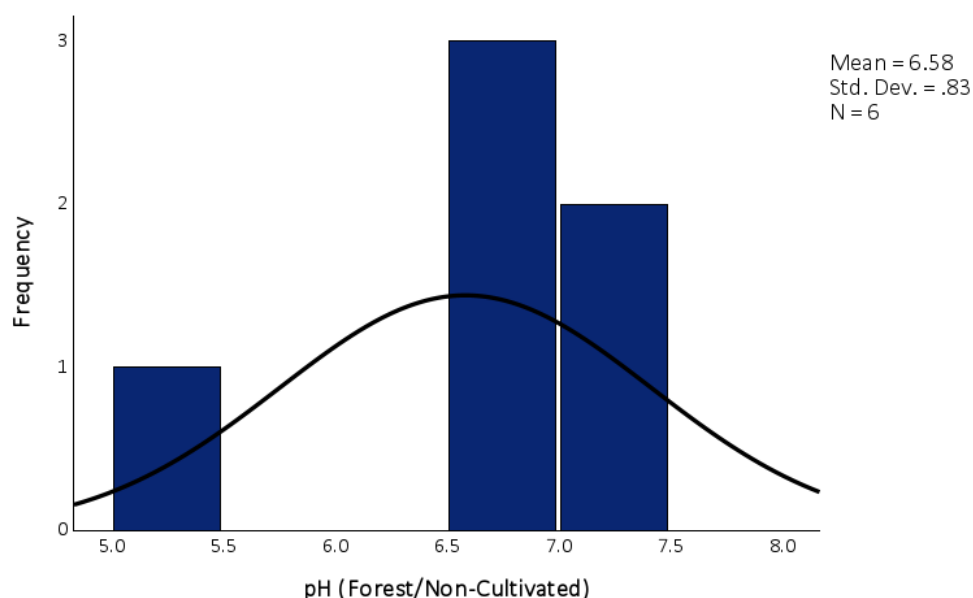


Figure 6.6. pH values of soil sampled in six forest/non-cultivated areas from Mexico and Belize.

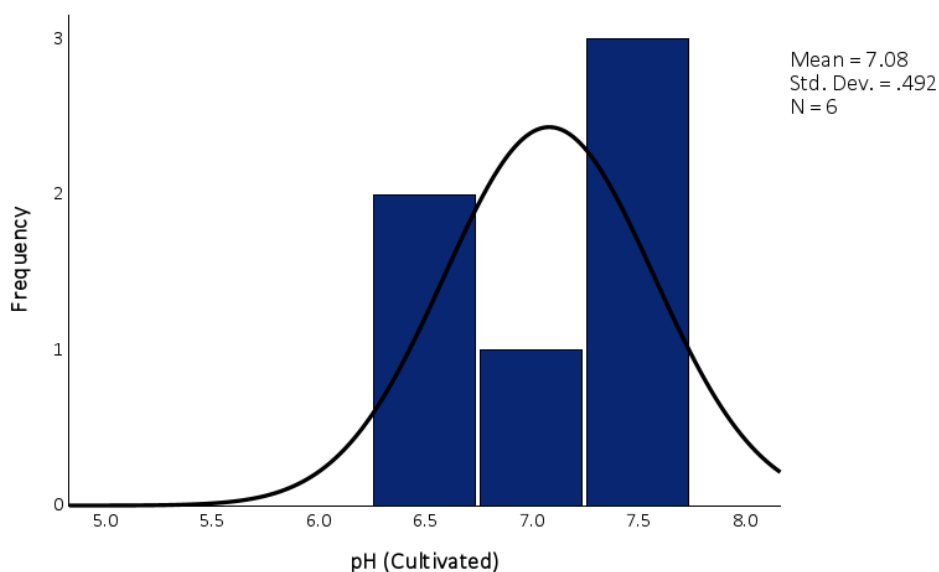


Figure 6.7. pH values of soil sampled in six cultivated plots from Mexico and Belize.

5.4.7. Primary Essential Nutrients (Extractable Nitrate/ $\text{NO}_3\text{-N}$, Potassium/K and Phosphorus/P)

Nitrate nitrogen or nitrate ($\text{NO}_3\text{-N}$), phosphorus (P), and potassium (K) are important nutrients that contribute to plant growth and can provide a useful indicator of soil quality (Weil and Brady, 2016; for methods see Chapter 3; Section 3.8.2.1). Results of the macronutrient analysis showed that extractable (also referred in the literature as available) $\text{NO}_3\text{-N}$ varied between 226.80 and 411.20 ppm with mean value of 294.98 ± 71.57 (Table 5.19; Figure 5.8) and a coefficient of variation of 24.3% which shows medium variability in the studied plots.

When compared across countries, Belize showed the highest values between 235.40-411.20 ppm with mean value of 342.35 ± 75.08 ; while Mexico showed values between 226.80-267.60 ppm, with a mean value of 247.60 ± 18.15 (Table 5.19). Higher levels of nitrate in Belize were expected since chemical and manure fertilization are used interchangeably in the sampled plots. Manure is a high source of nitrogen and the use of it in addition to chemical fertilised can result in high levels of $\text{NO}_3\text{-N}$.

Table 6.19. Descriptive Statistics of extractable NO₃-N (in ppm) in eight studied plots in Mexico and Belize.

NO ₃ ⁻ N	Mean	N	Std. Dev	Median	Min.	Max	Variance	Range
MX	247.60	4	18.15	248.00	226.80	267.60	329.28	40.80
BZ	342.35	4	75.08	361.40	235.40	411.20	5636.97	175.80
Total	294.98	8	71.57	262.20	226.80	411.20	5121.98	184.40

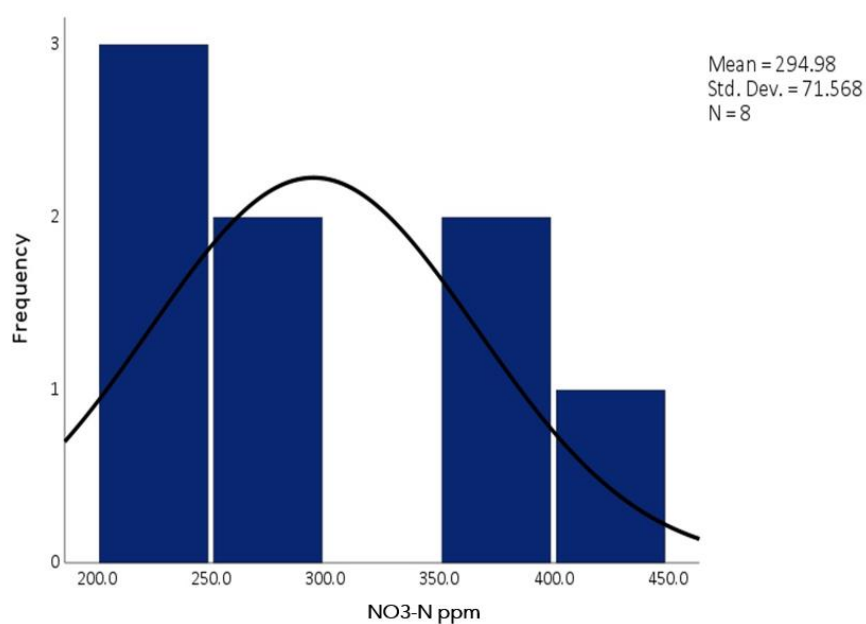


Figure 6.8. Extractable NO₃-N values of soil sampled in eight cultivated plots from Mexico and Belize.

In relation to the available P overall values range between 1-19 ppm with a mean of 10.50 ± 6.70 (Table 5.20; Figure 5.9). The coefficient of variation for available phosphate was 63.8% which shows very high variability in the studied plots. When compared across countries Mexico's showed values between 1-19 ppm and a mean of 10.25 ± 9.57 , just under the Belize mean of 10.75 ± 3.594 with values between 6-14ppm (Table 5.20).

Table 6.20. Descriptive Statistics of extractable P (in ppm) in eight studied plots in Mexico and Belize.

Phosphate (P)	Mean	N	Std. Dev	Median	Min	Max	Variance	Range
MX	10.25	4	9.570	10.50	1	19	91.583	18
BZ	10.75	4	3.594	11.50	6	14	12.917	8
Total	10.50	8	6.698	11.50	1	19	44.857	18

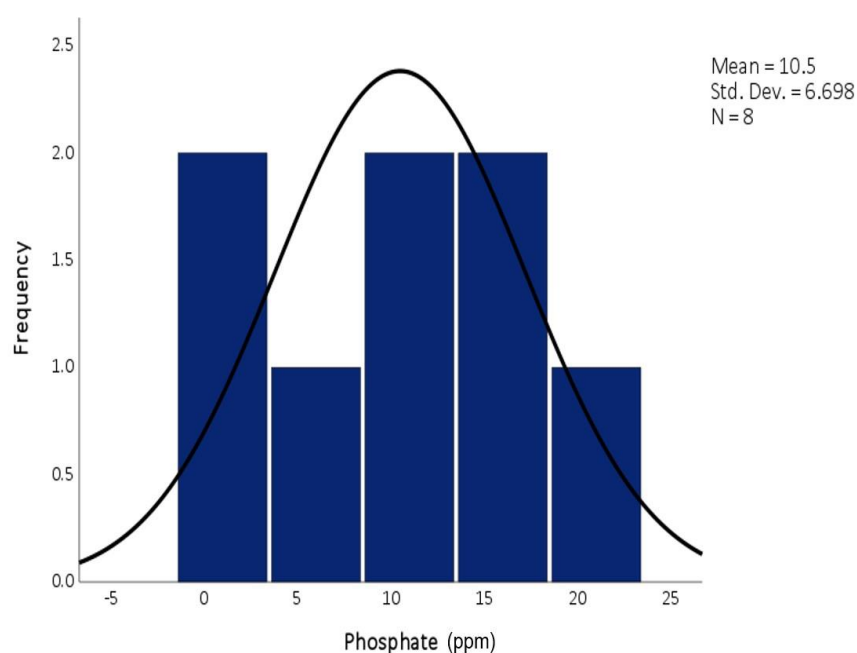


Figure 6.9. Extractable phosphate (P) in soil sampled in eight cultivated plots from Mexico and Belize.

In relation to available K overall values range between 30-120 ppm with a mean of 75.63 ± 36.10 (Table 5.21; Figure 5.10) The coefficient of variation for available K was 47.7% which shows very high variability in the studied plots. Mexico plots showed a mean of 102.5 ± 28.43 higher than Belize with a mean of 48.75 ± 17.50 (Table 5.21).

Table 6.21. Descriptive Statistics of extractable K (in ppm) in eight studied plots in Mexico and Belize.

Potassium (K)								
	Mean	N	Std. Dev	Median	Min	Max	Variance	Range
MX	102.50	4	28.43	115	60	120	808.33	60
BZ	48.75	4	17.50	47.50	30	70	306.25	40
Total	75.63	8	36.10	65	30	120	1303.13	90

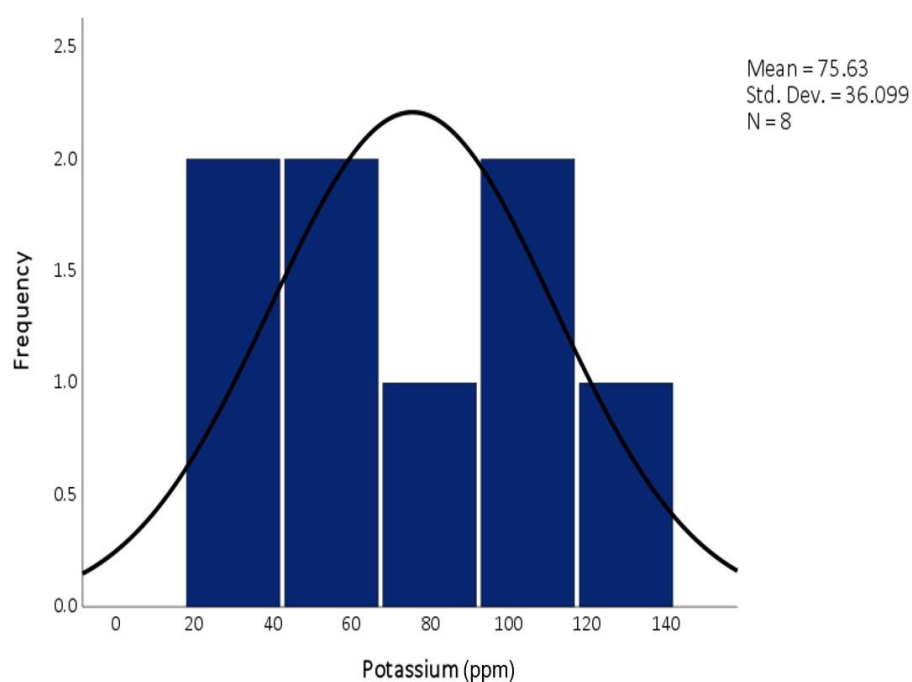


Figure 6.10. Extractable potassium (K) in soil sampled in eight cultivated plots from Mexico and Belize.

When comparing six cultivated plots with adjacent forest/non-cultivated areas results showed that NO_3^- , K and P values were higher in forest/non cultivated areas with values of 313.02 ± 211.83 , 85 ± 10.49 and 11.67 ± 13.71 respectively compared to cultivated areas with values of 292.90 ± 74.92 , 72.50 ± 36.65 and 9.17 ± 6.79 respectively (Table 5.22; Figures 5.11-5.13).

A t-test for paired samples showed that for all three nutrients difference between forest and cultivated areas was not statistically significant, for phosphate $t(5) = 0.33$, $p = .755$, 95% Confidence interval $[-17.01, 22.01]$. For potassium $t(5) = 0.69$, $p = .524$, 95% Confidence interval $[-34.41, 59.41]$ and for Nitrate-Nitrogen $t(5) = 0.28$, $p = .794$, 95% Confidence interval $[-167.45, 207.68]$.

Table 6.22. Descriptive statistics of cultivated vs non cultivated areas for soil attributes NO₃-N, K and P (in ppm)

	N	Minimum	Maximum	Mean	Std. Deviation
NO ₃ - N (C)	6	226.80	411.20	292.90	74.92
NO ₃ - N (F)	6	44.70	624.00	313.02	211.83
Potassium (C)	6	30.00	120.00	72.50	37.65
Potassium (F)	6	75.00	100.00	85.00	10.49
Phosphate (C)	6	1.00	18.00	9.17	6.79
Phosphate (F)	6	1.00	38.00	11.67	13.71

C=Cultivated F= Forest/Non-cultivated

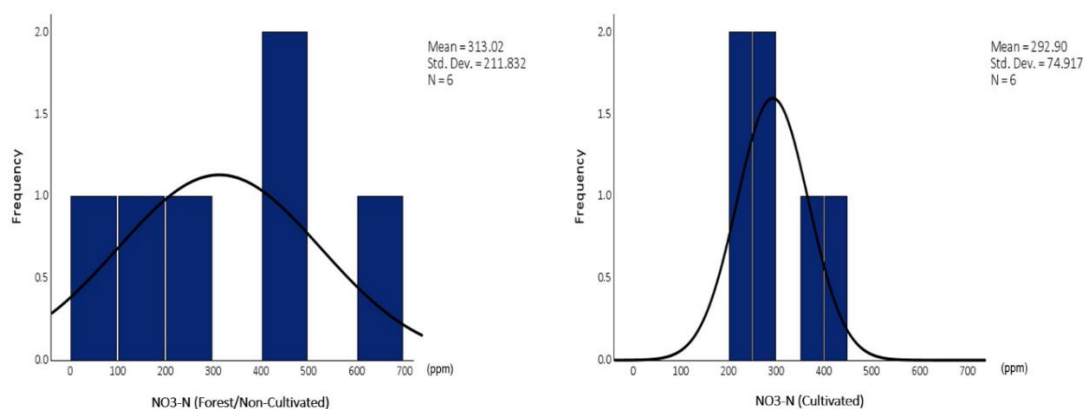


Figure 6.11. Extractable NO₃-N values in soil sampled in six forest/non cultivated and cultivated plots from Mexico and Belize.

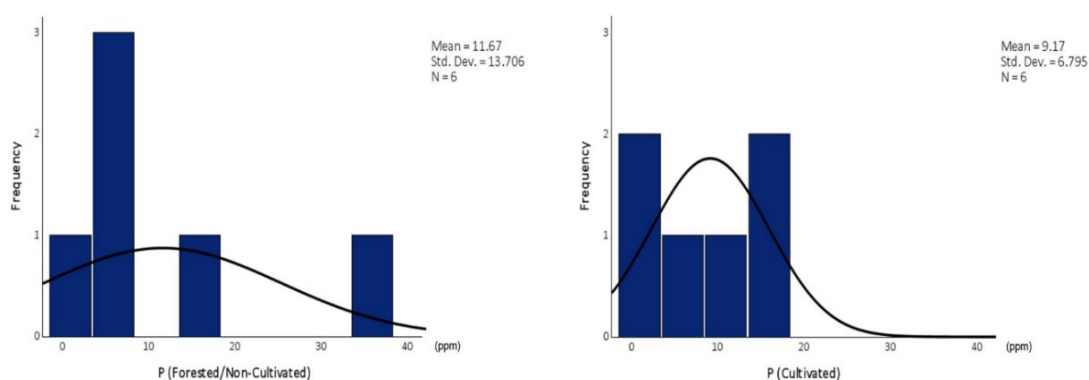


Figure 6.12. Extractable P in soil sampled in six cultivated plots from Mexico and Belize.

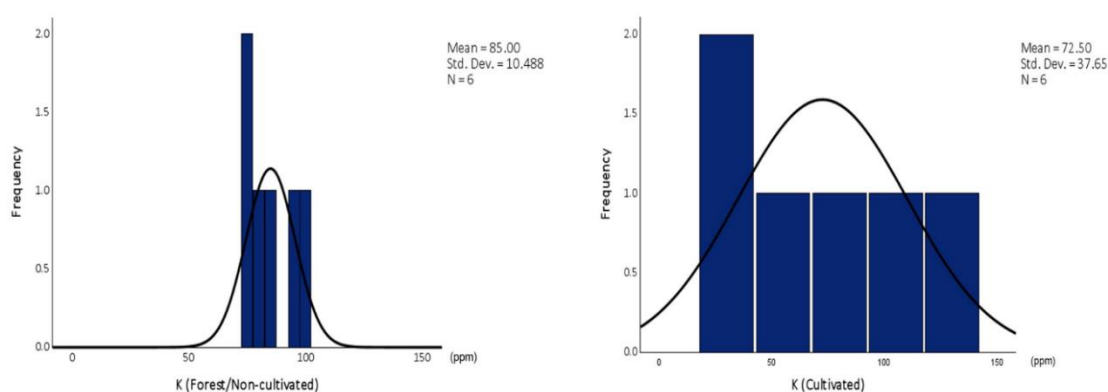


Figure 6.13. Extractable K in soil sampled in six forest/non cultivated and cultivated areas from Mexico and Belize.

When comparing plot management with nutrient availability, intercropped systems showed the highest level of potassium compared to rotation and monoculture. Rotation showed the highest level of extractable $\text{NO}_3\text{-N}$ compared to intercropped and monoculture, but the lowest level of Phosphate. Monoculture showed the highest level of extractable P but the lowest levels of $\text{NO}_3\text{-N}$ and K (Figure 5.14).

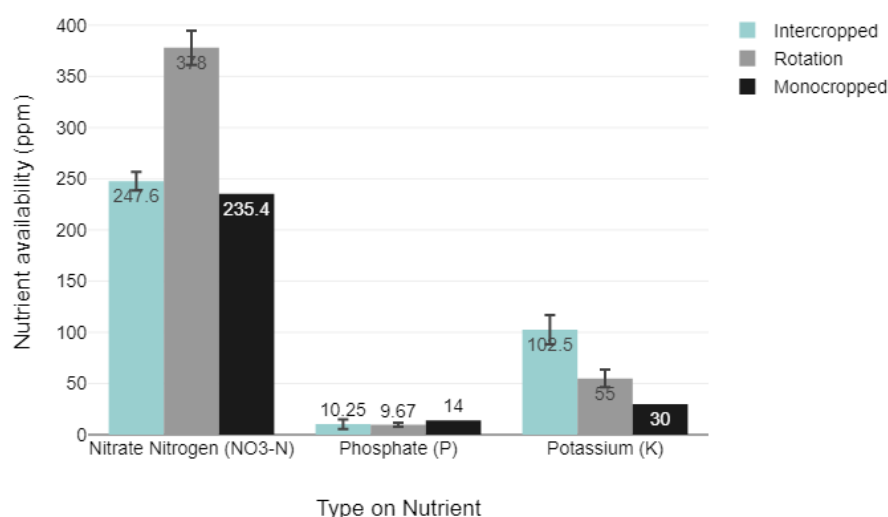


Figure 6.14. Mean and Standard deviation of nutrients in relation to the crop management in eight plots in Mexico and Belize.

Similarly when comparing the two most common types of fertilization (biofertilization and combined) used by farmers in relation to extractable nutrients (Table 5.23) the results of the descriptive statistics show that biofertilization had higher values for the variable

Phosphate ($M = 13.33$, $SD = 8.96$) than the combined group ($M = 10.75$, $SD = 3.59$). A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between biofertilization and combined with respect to the dependent variable Phosphate was not statistically significant, $t(5) = 0.54$, $p = .615$, 95% confidence interval $[-9.82, 14.98]$.

In relation to potassium, the descriptive statistics show that the biofertilization group has higher values for the dependent variable Potassium ($M = 98.33$, $SD = 33.29$) than the combined group ($M = 48.75$, $SD = 17.5$). A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between biofertilization and combined with respect to the dependent variable Potassium was statistically significant, $t(5) = 2.59$, $p = .049$, 95% confidence interval $[0.41, 98.76]$. The results of the descriptive statistics show that the biofertilization group has lower values for the dependent variable NO_3-N ($M = 254.53$, $SD = 14.34$) than the combined group ($M = 342.35$, $SD = 75.08$). two-tailed t-test for independent samples (equal variances assumed) showed that the difference between biofertilization and combined with respect to the dependent variable NO_3-N was not statistically significant, $t(5) = -1.95$, $p = .108$, 95% confidence interval $[-203.39, 27.76]$.

Table 6.23. Descriptive statistics of types of fertilization (biofertilization and combined) vs extractable phosphate, potassium and nitrate nitrogen values in ppm.

Nutrient	Type of Fertilization		Mean	Std. Deviation	Std. Error Mean
Phosphate (P)	Biofertilization	3	13.33	8.96	5.17
	Combined	4	10.75	3.59	1.8
Potassium (K)	Biofertilization	3	98.33	33.29	19.22
	Combined	4	48.75	17.5	8.75
Nitrate-Nitrogen (N-NO ₃)	Biofertilization	3	254.53	14.34	8.28
	Combined	4	342.35	75.08	37.54

5.5 Differences and similarities between farmer's characterization of soils and scientific analysis across countries

Although farmers are not familiar with the concept of organic matter or pH, nor appear to understand the connection between nutrient availability and soil health scientifically speaking, participant observation indicated that years of experience have provided them with the ability to visually identify “the needs of the plant”.

Overall, soil types and characteristics in relation to structure, colour and topographic position based on farmers descriptions are consistent with those based on numerical measurements and align with previously integrated approaches in relation to soil considered in other farm systems monitored in Yucatan in relation to these characteristics (Bautista et al., 2003).

When comparing soil texture described in the literature, these characteristics were like those provided by farmers for Farms 1, 3 and 4 in Yucatan, Mexico. Farmers descriptions for Farm 6 and Farm 8 in Belize in relation to particle size distribution and soil texture were very similar to the scientific descriptions. Farm 5 and 7 soil assessments aligned with some of the characteristics provided by the farmers, but since not much detail was given, it was hard to compare. With the information available it can be inferred that farmers in Belize also have knowledge of soil properties based on long term visual observations of their plots (De Souza et al., 2016).

Farmers' worldviews consider that the *monte* has been altered due to human actions and by not respecting the lords of the *monte*, these alterations come from some activities that are performed within the *milpa* such as the use of "poisons" (fertilization and pest control). Many farmers argue that the *monte* is 'tired' and that using "poisons" can help to make it fertile, however there is also a sense that this same action has altered the natural balance of earth. Although there is a lack of familiarity with the concept of organic matter (as mentioned above), when the concept and importance of organic matter was explained to farmers; several of them associated OM with "the natural balance of earth".

High levels of OM have been reported in *milpa* cultivation in previous studies in Yucatan (Bautista et al., 2003;2004; Ramirez-Silva et al. 2021) given the geographical features of the region. In Belize, previous reports of OM for *milpa* plots have been done in San Jose Succotz from Arnason et al. (1982) reporting values of O.M 20.2 ± 2.5 % while, in Indian Church, Orange Walk values of 13.4 ± 0.5 % were reported. Spurney and Cavender (2000) reported values of 6.5 % for Cayo District in Western Belize in plots near Spanish Lookout under conventional agriculture for maize and beans while in Toledo's Southern district, values of 12.2% in soils cultivated under *milpa*. Results obtained from this research fall within this ranges and aligned with those available in San Jose Succotz. However currently there are no updated baselines, to compare how much this variability occurs within different types of agriculture across districts. Future research and

government agricultural assessments should prioritize collecting data about OM under different agricultural crop management. The results obtained in this research although not enough indicated that OM in Belize variates across districts under different types of agricultural management and types of soils.

The values obtained for each of the attributes mostly reflect a high heterogeneity in all the studied plots and although soil fertility has not been monitored frequently, overall it appeared that small changes have occurred in soils in Mexico managed under intercropping compared to those in Belize. This could be a reflection not only of the diverse management practices adopted by farmers in response to the drivers that guide their farming system, but also it also reflects that current agricultural institutional frameworks have given farmers poor quality guidance around soil fertility which could bring potential impacts to local agriculture and food security in the long term if not addressed by local institutions.

Linking indigenous characterisations with scientific analysis of soil properties allowed for the evidence about the similarities and differences in soil properties at local scale (Slegers, 2008) to be transmitted to farmers who took part in the research through community workshops. This also provided an opportunity to highlight the importance and benefits of considering and continuously assessing local specific conditions, particularly soil and its attributes, using experiential observations and scientific data. Within this research linkage of knowledges proved to be useful for gathering some evidence of Belize's soil heterogeneity, particularly given the lack of baselines available for the country and which appeared to be like that reported for Yucatan.

Despite the usefulness of linking knowledges, the limited soil assessments available continue to be done through use of techniques and measures framed under scientific knowledge systems rather than work on integrated approaches that consider and integrate cultural ecology or indigenous knowledge systems. In Belize given the high dependency of the country on agriculture and a high tendency to prioritise productivity, which influences current management practices, a lack of proper regular and integrated soil assessments could pose a high risk to soil functionality and therefore to local food security; but also to the survival of the already fragmented indigenous knowledge associated with soils.

Although there were differences between approaches to soil assessment across countries and which reflect the lack of baselines, indigenous knowledge proved to be a common approach to understand soil quality in *milpa* plots in both countries.

Incorporation of scientific soil assessments and farmers' perspectives, values and worldviews are crucial since they can directly affect decision making that impacts local production (Chambers, 2005; De Souza et al., 2016). Decision-making processes are "dependent on how farmers judge soil quality in order to choose the appropriate agricultural practices to be used in cultivation" (p. 4). This was particularly important in this research given that replication of management strategies was a common practice documented in both countries amongst Maya farmers during participant observation. This challenge should be addressed by local agencies and institutions working with farmers in soil and agricultural related matters.

5.6. The influence of environmental policies, management strategies and modern practices on soil properties and knowledge systems around soil: Insights from Mexico and Belize.

5.6.1 Policies and government programmes targeting soils in Mexico and Belize
Soil is currently subject to a variety of international agreements (UN, 2021), however there is currently no single policy dedicated to soil at the United Nations (UN), unlike other environmental items such as water (Royal Society, 2021). Internationally this is reflected in regional and local policies and agreements by country.

Mexico and Belize have guidelines and principles in place related to land management and soil, however there is a great gap between the countries frameworks and legislations when addressing soil. Mexico has been part of different international treaties in terms of environmental legislation since 1989. At the national level there are several laws and regulations under its environmental legislation that have assigned different norms and standards. Each of the laws has its own regulations and is applicable to different environmental aspects: water, soil, air, climate change, waste, wildlife, among others. Local and municipal laws, agreements and decrees arise from these laws and are subject to the local context of each state (SEMARNAT, 2022).

In Mexico the instruments that can provide some information related to soil characteristics are included within the National and Forest Soil Inventory and the National Forest Monitoring System which are regulated under the Law of Sustainable

Rural Development by the National Forest Commission (CONAFOR) and the Ministry of Environment and Natural Resources (SEMARNAT, 2022). The national inventory provides information on the current state of soils by state; however the database only provides information regarding soil depth and dominant slope. Mexico also has the National Institute of Sustainable Land which is regulated under the Ministry of Agrarian, Territorial and Urban Development dedicated to “sustainable land management”. Within this institute in 2022 they launched the first National Land Policy (PNS Spanish acronym) which is a technical document that includes criteria for decision-making but only regarding local urban development and there is no mention about soil characterisation and soil health. A common thing observed during the review of policies and regulations is a trend in depicting land and soil interchangeably without a proper definition of these terms and misleading the interpretation of regulations.

Belize is also part of different multi-lateral agreements and programmes (United Nations, Caribbean Community, etc), but compared to Mexico it has significantly fewer environmental policies, although it has been working on new policies and frameworks targeting soil management. Nationally, the Environmental Protection Act enacted in 1992 and regulated by the Department of the Environment (DoE) is the main instrument that regulates different environmental elements in Belize such as water, flora, fauna, atmosphere, soil amongst others in relation to pollution, conservation, management and environmental impact assessment (Department of the Environment, 2023).

The most recent framework implemented by the Government of Belize (GoB) in relation to land management (and that includes soil health) began through the National Land Use Policy Framework, 2019 which is a revised and updated version of the 2011 National Land Use Planning Framework for Land Resource Development. The main target of the 2019 Policy Framework is to address issues related to land degradation through focusing on different sectors and targets through sustainable agriculture, soil management and forest rehabilitation projects that involved different stakeholders across the country. This framework is supported by the Land Degradation Neutrality Target Setting Programme (LDN TSP), an initiative from the United Nations Convention to Combat Desertification (UNCCD) to define national baselines and set targets for countries to achieve Land Use Neutrality by 2030 with the support of national policies and plans, and legislative tools (Ministry of Natural Resources, 2020). There has been some ongoing work targeting soils in Belize as shown in Table 5.24.

Table 6.24. Different frameworks implemented in Belize that address land management

Framework	Description
National Food and Agriculture Policy 2015-2030	Focused on growth of the agricultural industry, improve soil health (for productivity) and promotion of sustainable agricultural programmes.
SOILCARE Project	Initiative funded by the Global Environmental Facility (GEF) across different Small Island Developing States (SIDS) to strengthen capacities to prioritise actions aimed to restore degraded lands focused on the northern districts of Belize particularly Libertad and Patchakan due to inappropriate agricultural practices (monocropping systems).
National Determined Contribution through the National Climate Change Policy, Strategy and Action Plan	Focused on strengthening resilience to climate change effects through different sectors including agriculture and which will focus on improving and adopting better practices related to crops, soil, water and better information related to meteorological forecasts (National Climate change Office, 2017).
National Agriculture Sector Adaptation Strategy	To address climate change through actions that overcome gaps in technology relevant to crop production.
Belize Climate Change Action Plan	To build capacity and resilience around the challenges of climate change through involving key sectors including agriculture to enhance food security and sustainability.
Belize's UNCCD National Action Programme (2014)	Reflects the strategy to follow for prevention and mitigation of land degradation.
Other frameworks: National Adaptation Plan for Agriculture National Reducing emissions from deforestation and forest degradation (REDD+) Strategy 2020	

A review of frameworks in both countries revealed some gaps in relation to prioritising the natural and local human capital of soil, a common gap in many frameworks across the globe particularly in relation to climate change. In addition to this, although the frameworks address issues related to soil management and enhancing agricultural

practices (such as promoting intercropping systems and agroforestry in Belize), they do not focus on monitoring soil quality which is crucial for decision making. This gap could pose a challenge to national soil security given that management strategies adopted by farmers depend on perception of soil quality. De Souza et al. (2016, p.4) argue that “wrong soil quality judgment leads to agricultural management that can cause soil degradation and so compromise soil quality and agricultural sustainability”.

In multicultural countries such as Mexico and Belize, it is crucial to ensure participatory governance when implementing different frameworks that involve land management to achieve soil security and in the case of small-scale agriculture to understand the potential of traditional systems when building resilience to challenges such as climate change and food insecurity.

A lack of consideration of the natural and local human capital of soils can have a direct impact on the farmer’s decision making around management which will indirectly impact soil quality based on their way of perceiving and prioritising soil and the environment. Although sustainable soil management has been placed as a key action to achieve different sustainability goals, it appears that Mexico and Belize’s policies and frameworks around soils are still very limited and present important technical, political and social barriers that limit the development of adequate soil policies. This translates into inadequate soil management strategies and limited soil research which align with what has been found in several countries in Europe (Vanino et al. 2023).

5.6.2 Management Strategies and Knowledge systems around soil in Mexico and Belize

Knowledge of soil in Mexico and Belize has been acquired by farmers’ experience but also from different institutions and sources that farmers have access to in each country. A thematic analysis regarding land management performed amongst each of the case studies showed soil issues as a recurrent topic when referring to *milpa* management, but in terms of a consequence of the impacts of challenges such as climate change, rather than a rooted issue originating from soil management and from a lack of baseline in terms of soil fertility and quality. In Mexico and Belize soil fertility appeared to be directly linked to two constraints: rainfall variability and use of chemicals (“poison”). Although there is a shared perception of soil characteristics rooted in empirical observations of the landscape and having worked the land for a long period (De Souza, 2016), perception of

soil fertility has been influenced by external drivers mostly through government aid programmes and research collaborations in Mexico and agricultural extension services in Belize that work closely with farmers (Table 5.25). In addition to the drivers for practicing *milpa* (Chapter 1) the level of involvement within different programmes has shaped the management of soils and has influenced knowledge systems associated to them.

Table 6.25. List of public and non-public institutions involved with farmers in Mexico and Belize (Adapted from the Global Forum for Rural Advisory Services; GFRAS, 2012)

	Public Institutions	Non-Public institutions
Mexico	Regular government agricultural programmes Peso por Peso, Proagro, Procampo, Desarrollo para el Bienestar	Private Research Centres (eg. CIMMYT)
	Focalized agricultural programmes (e.g. Sembrando Vida/Sowing Life)	Farmers-based associations, ejido cooperatives and societies
	Public Research Centres (Eg. Yucatan Scientific Research Center -CICY)	
Belize	Ministry of Agriculture, Food Security and Enterprises	Private agro-business
	Central Farm, Caribbean Agricultural Research and Development Institute (CARDI)	National and International NGOs
	University of Belize	Farmers-based associations, cooperatives and societies

In Belize, the most common involvement of farmers in advisory/aid programmes is through the Ministry of Agriculture, Food and Enterprises and their national agricultural extension service. This extension service was introduced around 1920s and provides services to farmers through extension officers coordinated by a District Agricultural Officer (GFRAS, 2012). The main role of extension officers prior to 2020 was transfer of technology to farmers, data collection, impact assessment, agricultural census and

project activities implementation, however their role has evolved mostly into data collection (Sanchez, 2022, personal communication).

Overall, Belize has limited human resources appointed for agricultural advisory and extension services and there are very limited agricultural facilities in place to conduct soil and plant analysis. This translates into farmers having to depend on other knowledge sources for land management given discontinuous support from the extension service. Belize also has limited financial resources for implementing aid and training programmes and actions from their proposed frameworks involving agriculture, depending mostly on budgets from multilateral and bilateral donor agencies, development banks, emerging finance mechanisms and the private sector (e.g. Green Climate Fund-GCF, Global Environmental Facility-GEF, Land Degradation Neutrality (LDN) Fund, Adaptation Fund, multilateral development banks, regional development banks). This limits the capacity of the country to be able to address all the proposed actions. As a result, they must prioritise some over others and unfortunately in most cases these do not align with farmer's priorities (Sanchez, 2023 personal communication). Mexico has specific allocated national budgets and national institutions in charge of implementing aid and government agricultural programmes in addition to different private and international finance mechanisms however there is a disconnection between sectors and a high tendency for focusing on specific targets.

Gray and Morant (2003, p. 427) argue that “local and scientific knowledge systems come into contact through a long history of exchange and communication that has occurred between western and indigenous culture systems”. This was documented during the research since most of the cases studies and those surveyed expressed that throughout the years they are or have been part of government programmes aimed at providing aid and assistance to farmers in Mexico and through the extension service in Belize.

The level of involvement in aid and research programmes has not necessarily had a major influence on each country's perceptions in relation to soil quality but has had more impact on farmer's decision-making regarding land management. During the surveys, participant observation and interviews for the case studies in Mexico some of this influence was recorded, but in many cases, farmers were reluctant to speak about it, or provide further details especially when involved with government programmes.

“In the beginning I learned with Cimmyt in 2014 and the Cimmyt technicians arrived and they invited us to the workshops and from there I became interested in how it is prepared [biofertilizer] and how the process is and what is the advantage of using it and I see that it is the same that you use the chemical or that you use the BIOL, it has the same effectiveness”.

Farm 4, Xoy, September 2021

“Lately we have participated with the Cimmyt and we perceive that they want to seek that contextualization [to local characteristics] that we want... but unfortunately the Cimmyt is limited to providing seeds only and we want inputs that really allow us to take advantage of the crop, the use of the land. So, in that sense it is limited and what we would like is that they really provide us with the inputs that we really need.”

Farm 2, Oxxintok, September 2021

Farmers in Mexico involved in Sembrando Vida programme appeared to be more inclined to use fewer chemicals and there is more openness towards the use of alternatives such that they continue to enhance their capacity for experimentation and decide the best techniques and knowledge to be used.

Farmers in both countries, despite being exposed to modern techniques and considering them useful, continue to rely on and use traditional methods, as portrayed in the surveys. Overall farmers think that using modern techniques for agriculture is good/useful (54%); bad (17%); good but has negative impacts (14%); expensive (9%) and Not answered/Don't know (6%). However, when asked which method they prefer to use 54% indicated that traditional, 26% combined, 3% modern and 17% semi-traditional. Some thoughts shared around these perceptions are included in Table 5.26.

Table 6.26. Perception of farmers in Yucatan and Belize regarding the use of modern agricultural techniques

Good/Useful (54%)	<i>"I think is good because the hybrid really works if it's for business/sale"</i> Farmer, 76 years old, San Antonio, Cayo, Belize <i>"Is good because of the weather we are experiencing. We cannot control certain things like the plagues"</i> Farmer, 30 years old, Xoy, Yucatan, Mexico <i>"I think it's good because it makes things easier. It is good to use the traditional but also the modern like the irrigation. For maize is better to use mechanized but for other things is better by hand"</i> Farmer 65 years old, San Jose Succotz
Good but has negative impacts (17%)	<i>"Is good but it has a lot of consequences. Using lots of chemicals is destroying us, and it is affecting our health"</i> Farmer, 60 years old Patchakan, Corozal, Belize <i>"I think is important too [using new techniques], because we get money faster and we get more knowledgeable about agriculture, but we are learning that and forgetting our knowledge"</i> Farmer, 63 years old San Jose Succotz, Cayo, Belize <i>"These new technologies have benefited us in terms of working faster, however it still has brought us issues because no matter the way we work we always get bad yields"</i> Farmer, 61 years old, Tzucacab, Yucatan, Mexico
Bad (14%)	<i>"We have seen that with mechanized and the wind the milpa falls down. For us is very important to produce the native maize. It is important to take care of it because it lasts more, has more nutrients and better flavour."</i> Farmer, 43 years old, Xoy, Yucatan, Mexico
Expensive (9%)	<i>"Is better to do the traditional way because the materials are expensive"</i> Farmer, 50 years old, San Jose Succotz, Cayo, Belize <i>"They are very expensive"</i> Farmer, 37 years old, Maxcanu, Yucatan, Mexico <i>"Is good but we don't have the economy to have it"</i> Farmer, 63 years old Xoy, Yucatan, Mexico

Reasons to continue using traditional management have to do with a) learning process/cultural identity/tradition (37%), b) good yield (16%), c) no contamination or damage to nature (16%) d) low cost (11%), e) easy and have the physical conditions to practice it (11%), f) no other alternative (5.3%)

“I like it more, because we do it for our family, not as a business. We started this long time ago and I would like to continue practicing/doing it. Is something I don’t want to forget, because is something that we learnt since we migrated to Belice from Yucatan due to the War of Casts. Is something that have history and that history is beautiful”

Anonymous Farmer, 59 years old, Patchakan

Eighty-nine percent of the farmers surveyed stated that the reason for using a combined method was because it works and gets a good yield. It also has to do with their empirical experience (trial and error/self-experimentation) as a result of limited advice from either the extension service in Belize, or from other sources in the case of Mexico. The experimental approach has shown them the disadvantages of technology/modern approaches compared to the traditional way of doing things. Experiences have then played a big role in farmers perception of modern scientific techniques for management. They do recognize they are “faster” and practical, but are not necessarily effective, as they have witnessed failures, so they combined techniques and knowledges to achieve production. Finally, for all the farmers surveyed, the reason for using a semi-traditional method was because it is easier and less time consuming.

“Because it works. There are things that technology can really help with, it's easier and you don’t have to put too much effort. I don’t like trying so many new things because sometimes it goes wrong so it's better to the way you know”

Anonymous Farmer, 44 years old, San Antonio Belize

“These techniques allow for the workforce to be easier and it benefits us a lot because we don't have to spend too much energy in the milpa”

Anonymous Farmer, 50 years old, Maxcanu, Mexico

Some of these experimental approaches, however, are based on replicating strategies from neighbours or putting in place advice from agro-businesses without fully understanding of their micro-local soil conditions which again can impact soil quality and functionality in the long term.

Results from the surveys and interviews showed that there is also a high disconnection (despite the influence of western science in management) around the effect of such

management on crop yields, but also on how other abiotic elements such as climate and weather can not only impact crop yields but soil fertility. Farmers in both countries do not fully associate the interaction between climate and soil in relation to soil properties, but instead focus on soil productivity. In San Antonio for example, two visually similar soil types as found in Farms 5 and 6 can present different soil properties influenced by the microclimate in the community (Finch et al., 2014), however farmers do not necessarily see this as connected. The perception of changes in climate by each of the farmers can also indirectly influence how a farmer manages soil. This poses an additional challenge given that there is also a lack of familiarity around the potential impacts of climate variability on soil quality.

Based on the above, to understand farmers' priorities in relation to soil and other local conditions it is also important to understand their perceptions of associated elements to soil such as climate. This can contribute to addressing challenges associated with interconnected local environmental conditions (e.g. soil and climate) and the potential impacts that climate variability could have on soil properties. The impacts on social processes, such as community and knowledge resilience associated with such local environmental conditions, also need to be considered. The results of assessing climate variability in different communities where *milpa* is practiced, and how it is connected to soil, knowledge systems and culture, will be discussed in Chapter 6.

CHAPTER 6 Climate change and traditional agriculture: Insights in the context of the *milpa* Maya in Mexico and Belize.

6.1 Introduction

The present chapter focuses on the results of assessing climate variability in three Maya Yucatec communities, comparing meteorological data recorded from the nearest meteorological stations in the study areas, with perceptions of climate change from Maya Yucatec farmers. The first part of the chapter examines how climate variables (precipitation and temperature) have changed past and present (variability and trends) and then compared the results with farmer's intuitive perceptions of change.

Analyses were done for linear trends in total annual rainfall and annual mean of temperature at the community level in Peto in Yucatan, Patchakan in Northern Belize and Central Farm in Western Belize. To examine potential changes in climate within these communities the chapter also analyses the decrease or increase of rainfall and temperature with respect to the average (anomalies).

Information extracted from surveys and semi-structured interviews was used to provide insights into farmers' views and beliefs around climate change and variability, as well as the impacts of this on *milpa* systems and the adaptation strategies adopted. In doing so, the chapter also examines the role that both scientific and indigenous knowledge have played into adaptation and the potential impacts that climate change has had within this knowledge system.

6.2. Climate variability in Maya Yucatec communities in Mexico and Belize

6.2.1 Instrumental records in Maya Yucatec communities in Mexico and Belize

Results from the annual climatology for each of three Maya Yucatec communities showed that within the past 30 years (1991-2021) variable long-term conditions have been observed across Peto in southern Yucatan, in Central Farm in Western Belize and in Libertad in Northern Belize (See 3.7.2.1.2).

In Peto, Yucatan the wettest year was 2020 with a mean annual precipitation of 1567 mm and the driest in 1995 with 609 mm. In terms of temperature the average temperature was 27.34°C while the average maximum temperature was 38.29°C and minimum was 8.33°C. The hottest year was 2006 with a maximum temperature of 45°C (Fig 6.1.)

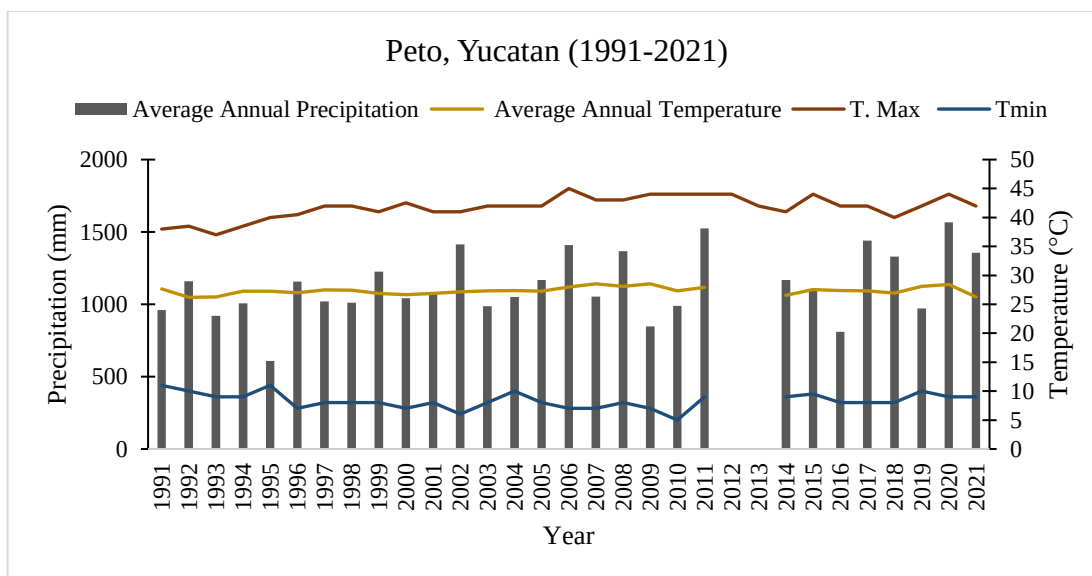


Figure 7.1. Average annual precipitation (mm) and temperature (°C) in Peto, southern Yucatan, Mexico (1991-2021).

At Central Farm, in western Belize 2013, was the wettest year with 1943.20 mm and the driest in 2019 with 955.80 mm. In terms of temperature an average temperature of 26.44 °C was reported, where average maximum temperature was 31.7°C and minimum was 21.2. The hottest year was 2019 with a maximum temperature of 33.1 (Figure 6.2).

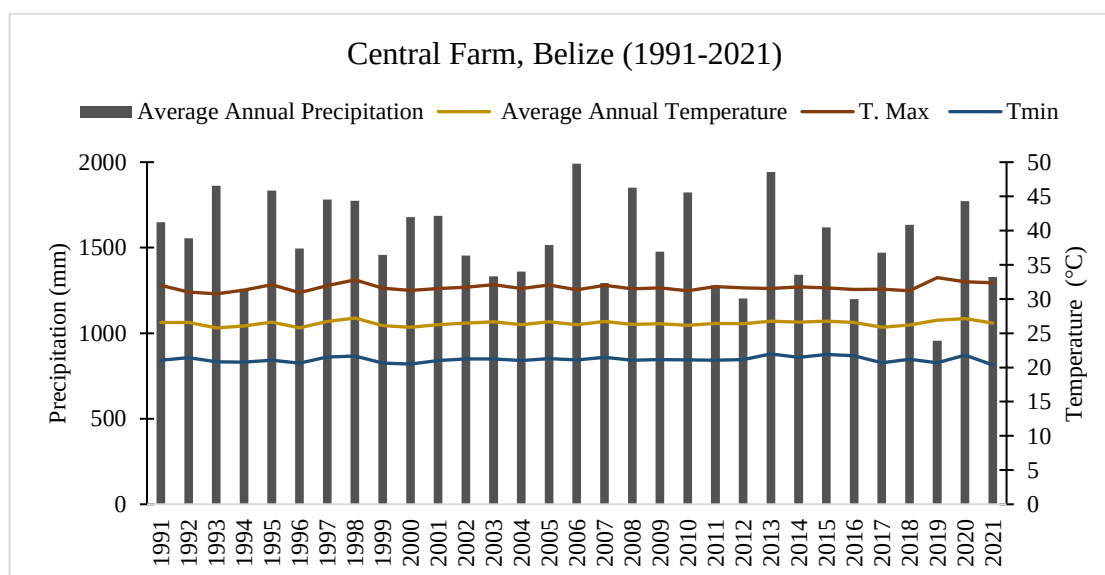


Figure 7.2. Average annual precipitation (mm) and temperature (°C) in Central Farm, Western Belize (1991-2021)

Libertad, in northern Belize showed that 2013 was also the wettest year with 2015.50 mm and the driest in 2018 with 772.30 mm (Figure 6.3). No data is available for temperature.

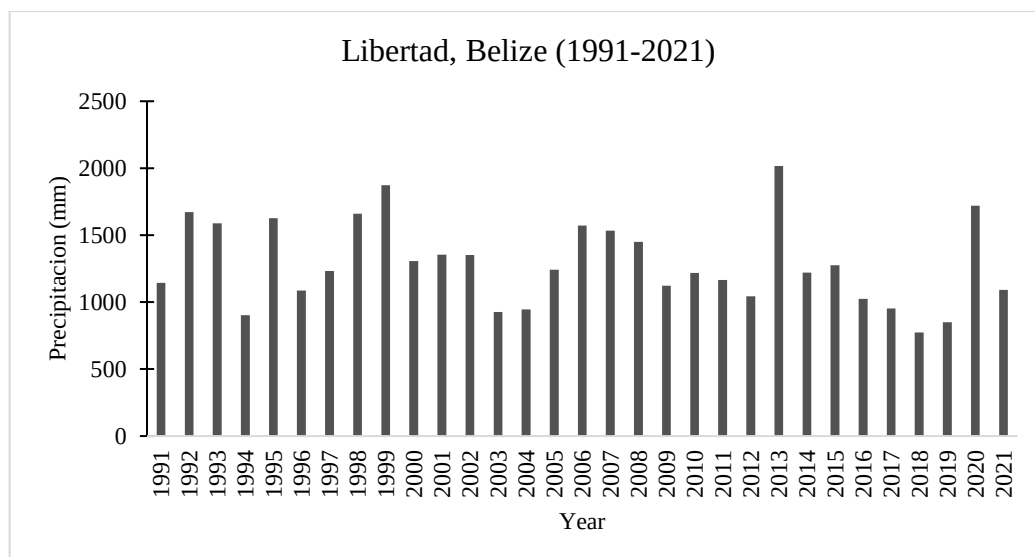


Figure 7.3. Average annual precipitation (mm) in Libertad, Northern Belize (1991-2021)

6.3 Changes in Precipitation

6.3.1 Average annual precipitation

Results from the average annual precipitation analysis (1991-2021), showed a long-term average of 1128.55 mm for Peto, Yucatan, 1544.41 mm for Central Farm, Belize and 1288.49 mm for Libertad (Figure 6.4). The one-factor analysis of variance (ANOVA) test showed that changes were significantly different across the three stations $F= 18.43$, $p<.001$ (Table 6.1).

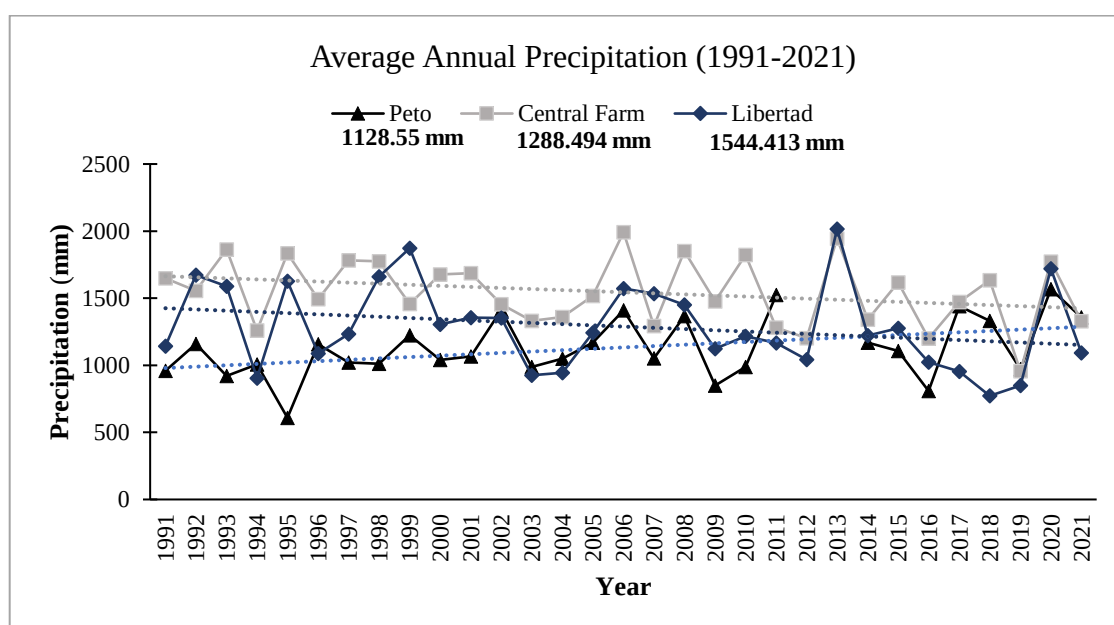


Figure 7.4. Average annual precipitation (mm) for three meteorological stations near the studied communities for the period 1991-2021.

Table 7.1. Summary of descriptive statistics and ANOVA analysis of average annual precipitation (mm) from 1991-2021 for three Maya Yucatec communities (Mx=Mexico; Bz=Belize).

Summary			Peto	Central Farm	Libertad		
Mean			1128.55	1544.413	1288.494		
Standard Error			41.82739	45.55243	56.6066		
Median			1066	1516.4	1233.5		
Standard Deviation			225.2474	253.6252	315.1722		
Kurtosis			-0.15941	-0.59527	-0.47207		
Skewness			0.104569	-0.16272	0.473765		
Range			958	1036	1243.2		
Minimum			609	955.8	772.3		
Maximum			1567	1991.8	2015.5		
ANOVA							
Source of Variation		SS	df	MS	F	P-value	F crit
Between Groups		2652895	2	1326447	18.43919	2.05E-07	3.100069
Within Groups		6330397	88	71936.33			
Total		8983291	90				

6.3.2. Long-term average monthly precipitation

Monthly average precipitation in Peto between 1991 and 2021 varied between 22.52 mm and 179.61 mm. The highest amounts of precipitation have been observed between May and October, September being the wettest. The lowest amounts of monthly precipitation occur between November and April with February being the driest. (Figure 6.5).

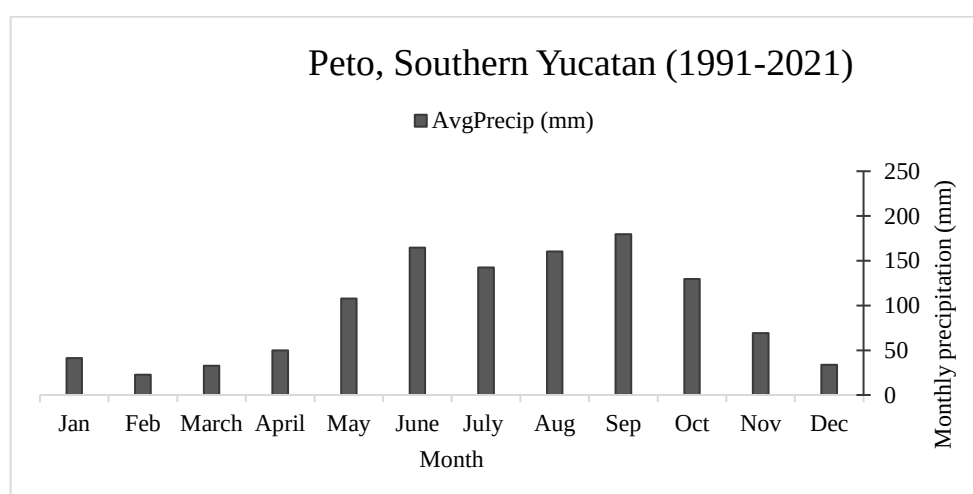


Figure 7.5. Monthly average precipitation (mm) in Peto, Yucatan. Mexico (1991-2021).

Monthly average precipitation in Central Farm, Western Belize was between 205.41 mm and 35.18 mm. The highest levels of monthly precipitation occurred between June and January with October the wettest month, the lowest level was from February to May with

April the driest. In terms of temperature the average monthly temperature May reported the highest average monthly temperature at 34.5°C (Figure 6.6).

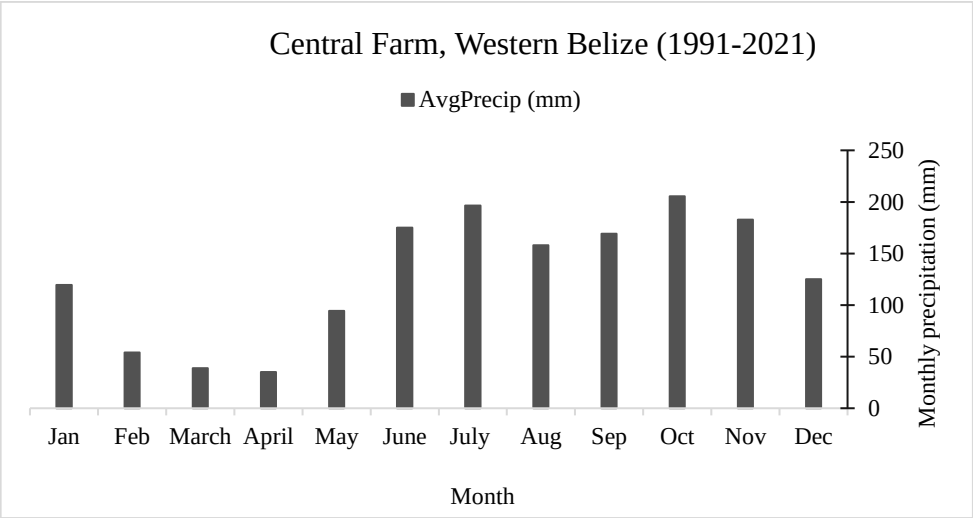


Figure 7.6. Monthly average precipitation (mm) in Central Farm, western Belize (1991-2021.)

In Libertad, Northern Belize monthly average precipitation was between 199.67 mm and 29.68 mm. Wet conditions were recorded between May and November where October was also the wettest, while drier conditions occurred between December and April, where March was the driest (Figure 6.7).

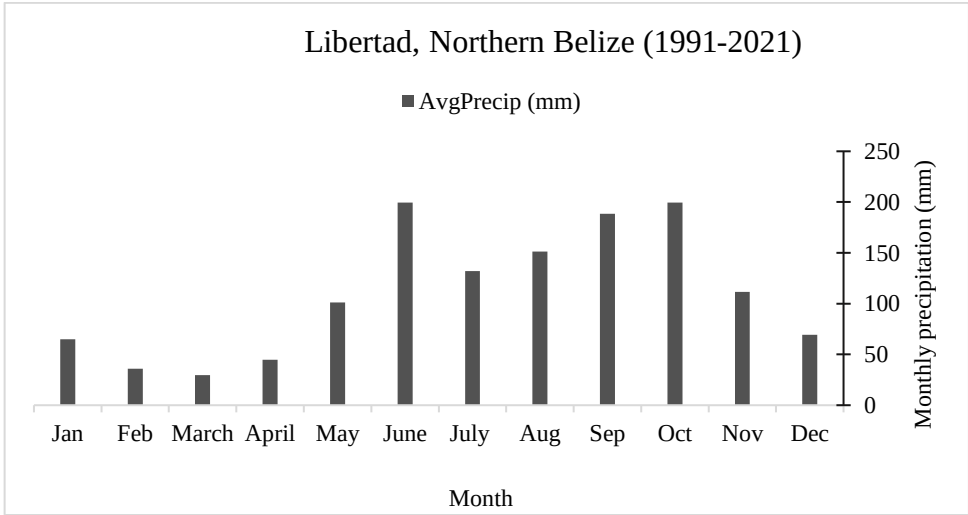


Figure 7.7. Monthly average precipitation in Libertad, Northern Belize 1991-2021.

The one-factor analysis of variance (ANOVA) showed that there was a significant difference between the monthly annual precipitation between the three communities across years $F = 19.18$, $p = <.001$ (Table 6.2). Results from statistics analysis also

showed that monthly annual precipitation has been more variable in Libertad (CV=0.23) than in Peto (CV=0.20) and Central Farm (CV=0.17).

Table 7.2. Summary of descriptive statistics and ANOVA analysis of mean monthly precipitation (mm) from 1991-2021 for three Maya Yucatec communities (Mx=Mexico; Bz=Belize).

Summary						
	Peto, Mx	Central Farm, Bz	Libertad, Bz			
Mean	94.30	129.47	110.56			
Standard Error	3.46	3.90	4.50			
Median	88.83	126.37	106.30			
Standard Deviation	18.62	21.71	25.07			
CV	0.20	0.17	0.23			
Kurtosis	-0.08	-0.24	-0.37			
Skewness	0.08	0.05	0.31			
Range	79.83	97.00	103.60			
Minimum	50.75	79.65	64.40			
Maximum	130.58	176.65	168.00			
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18610.99	2	9305.49	19.18	<.001	3.10
Within Groups	42703.45	88	485.27			
Total	61314.44	90				

When comparing monthly long-term precipitation of each community for the period 1991-2021 with that of 2021 (when the interviews were conducted), the station in Peto, Mexico reported an increase of 18.56 mm/year which also translated into a yearly total difference of 1133.46 mm in the 1991-2021 period to 1356.25 mm/year in 2021 (Figure 6.8). A t-test for paired samples was conducted to see if changes in monthly annual precipitation within the same station but within different periods were statistically significant. Results showed that in Peto changes were not statistically significant $t(11) = -0.99$, $p = .342$, 95% Confidence interval [-59.73, 22.59].

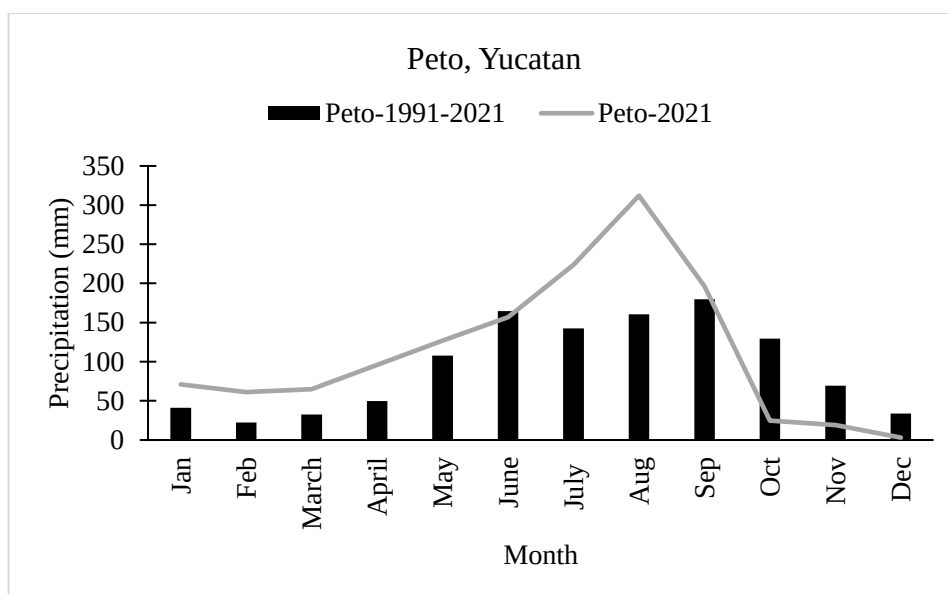


Figure 7.8. Differences in mean monthly precipitation (mm) in Peto, Mexico for 1991-2021 and 2021.

In the case of Central Farm there was a decrease of 18.75 mm/year and a change in yearly total precipitation from 1553.91 to 1328.90 mm/year. Results from the t-test showed that changes were not statistically significant, $t(11) = 1.12$, $p = .285$, 95% Confidence interval [-17.96, 55.46; Figure 6.9).

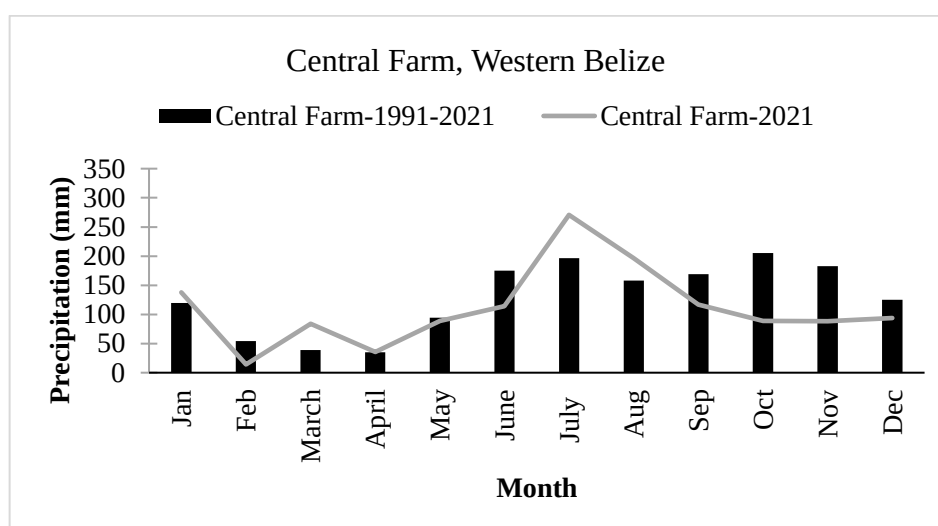


Figure 7.9. Differences in mean monthly precipitation (mm) in Central Farm, Western Belize for 1991-2021 and 2021.

Libertad also reported a decrease of 11.41 mm/year and a change in yearly total precipitation from 1328.59 to 1092.40 mm. The t-test also showed that this change was

not statistically significant, $t(10) = 0.23$, $p = .825$, 95% Confidence interval $[-38.23, 46.92]$; Figure 6.10).

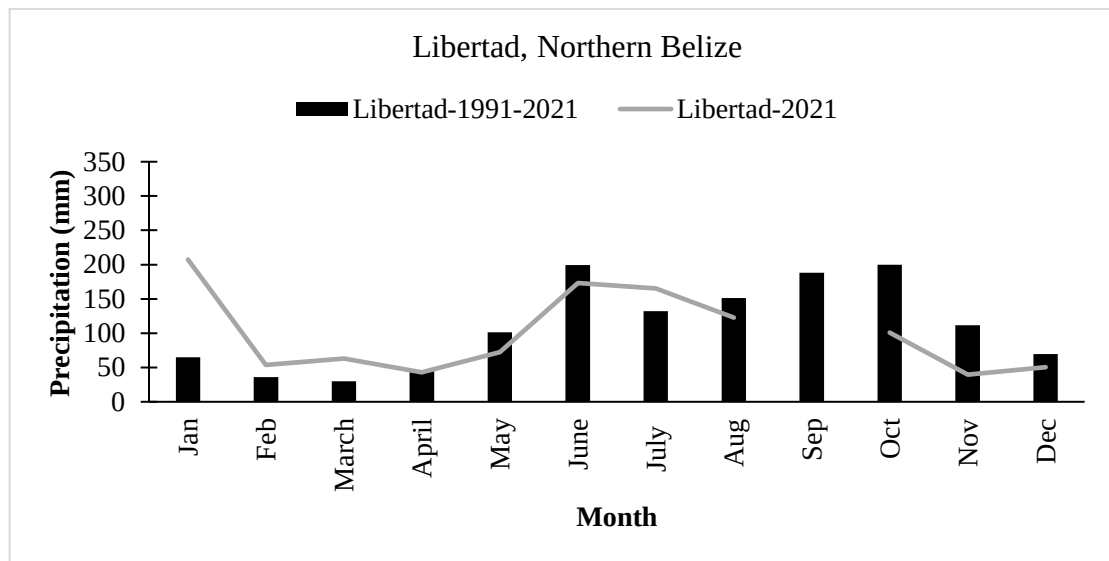


Figure 7.10. Differences in mean monthly precipitation (mm) in Libertad, Northern Belize for 1991-2021 and 2021.

6.3.2 Annual Precipitation Trends

Annual precipitation trends showed that southern Yucatan (Peto) presented a coefficient of increase of 10 mm/year. In contrast, western Belize (Central Farm) presented a coefficient of decrease of -7.96 mm/year while northern Belize (Libertad) presented the highest coefficient of decrease of -9.23 mm/year (Figures 6.11-6.13).

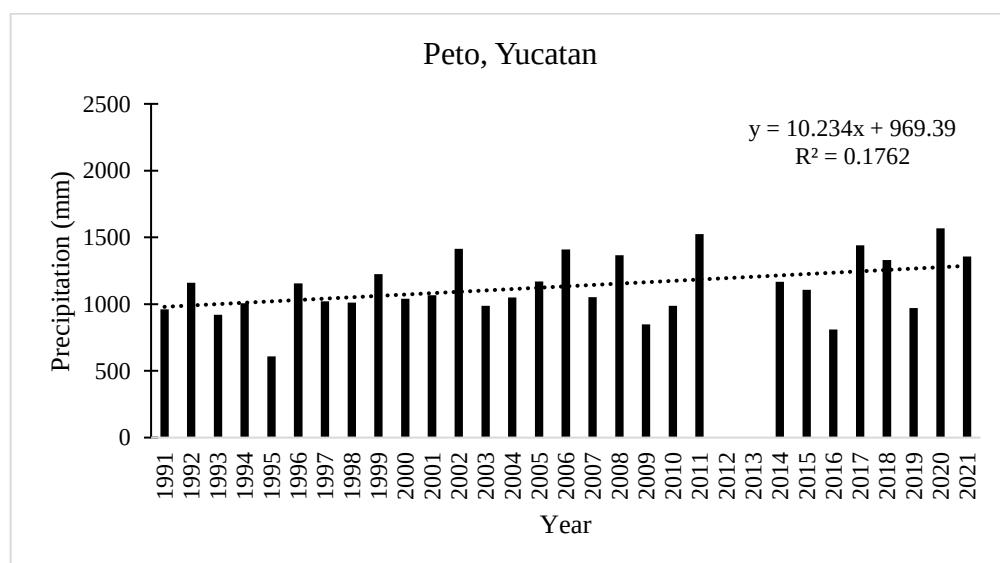


Figure 7.11. Annual precipitation trend for Peto, southern Yucatan, Mexico from 1991-2021.

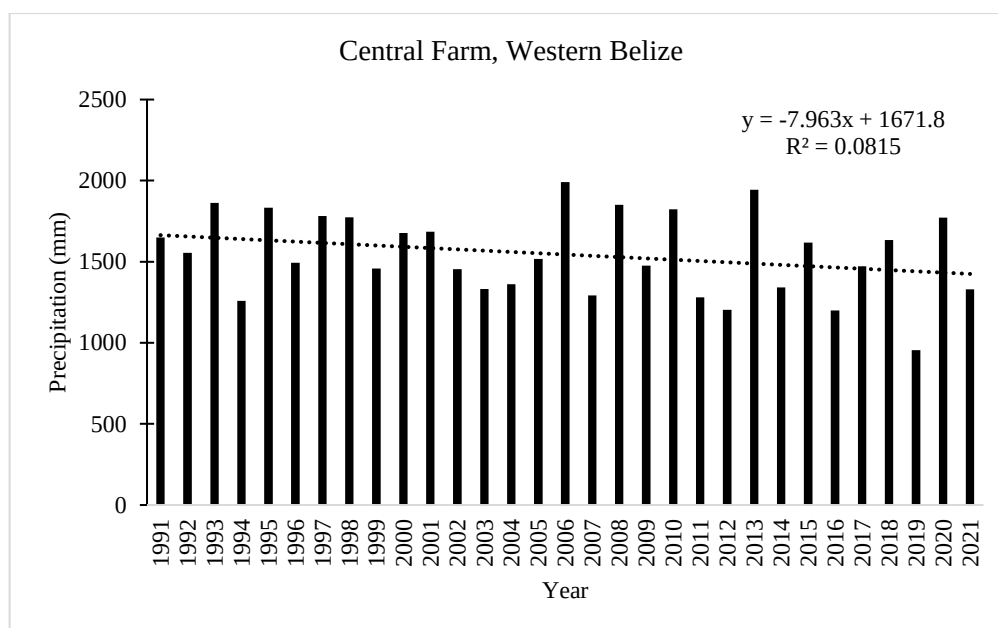


Figure 7.12. Annual precipitation trend for Central Farm, western Belize from 1991-2021.

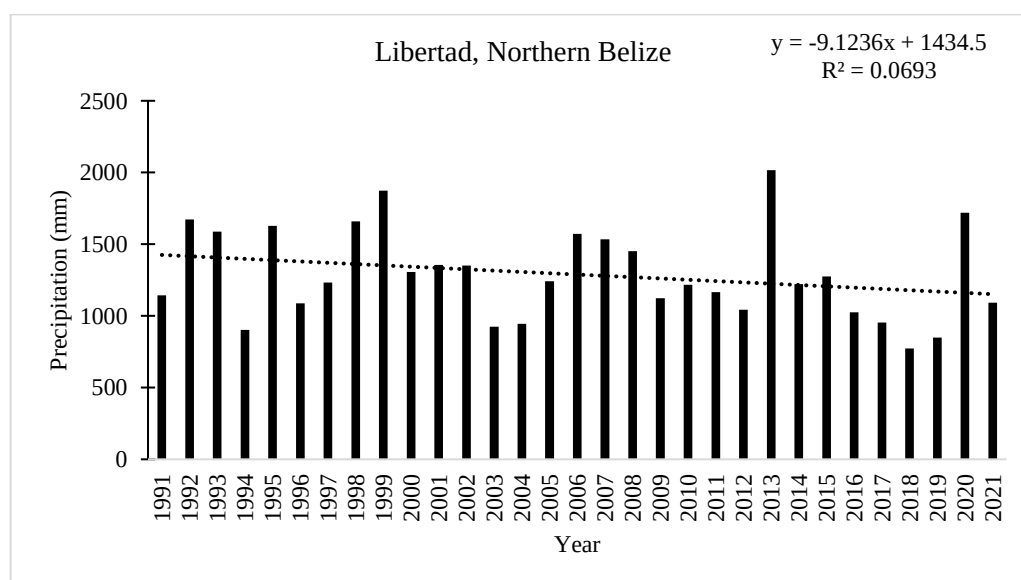


Figure 7.13. Annual precipitation trend for Libertad, Northern Belize from 1991-2021.

6.3.3. Changes in Monthly Average Precipitation across decades

Differences in the monthly average precipitation between the periods 1991-2001, 2002-2011 and 2012-2021 were conducted to examine significant changes across decades for each community. In Peto, Southern Yucatan, small changes have been observed across the three decades (Figure 6.14) particularly in relation to variability during the rainy season; however, the results from the ANOVA showed that there were no significant differences between periods $F = 0.07$, $p = 0.93$ (Table 6.3).

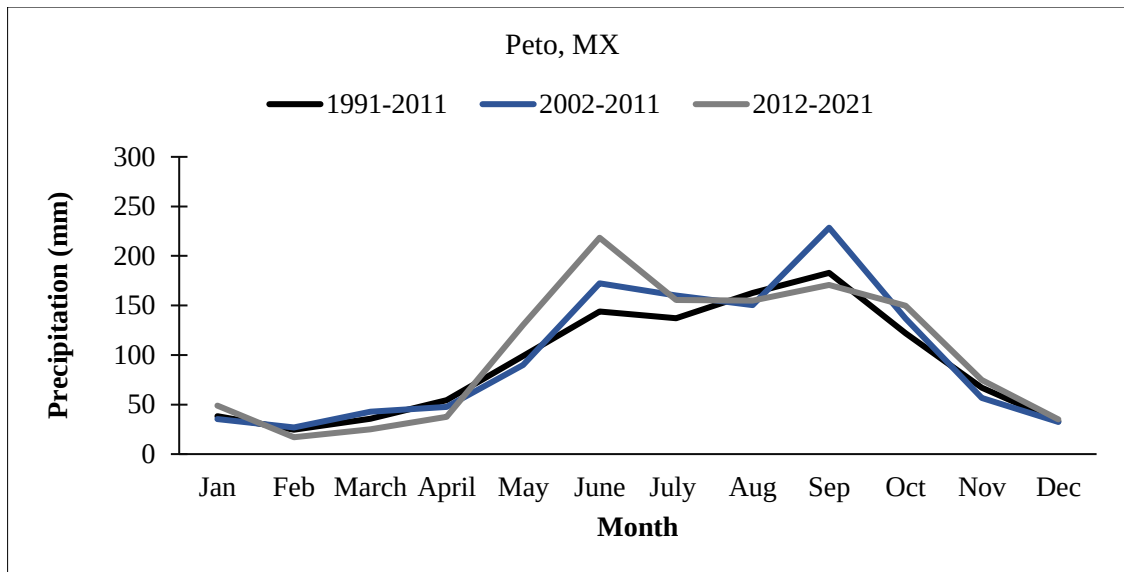


Figure 7.14. Differences in mean monthly precipitation (mm) for Peto station for the periods 1991-2011, 2002-2011 and 2012-2021.

Table 7.3. Descriptive statistics and ANOVA analysis of monthly average precipitation (mm) between the periods 1991-2011, 2002-2011 and 2012-2021 in Peto, Southern Yucatan.

SUMMARY						
	1991-2001		2002-2011		2012-2021	
Mean	91.73		98.39		101.54	
Median	83.09		73.45		102.63	
Standard Error	16.29		19.71		19.92	
Standard Deviation	56.42		68.29		69.01	
CV	0.62		0.69		0.68	
Kurtosis	-1.56		-0.99		-1.52	
Skewness	0.29		0.61		0.20	
Range	158.30		201.60		201.38	
Minimum	24.63		26.90		17.00	
Maximum	182.93		228.50		218.38	
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	602.00	2	301.00	0.07	0.93	3.28
Within Groups	138708.84	33	4203.30			
Total	139310.84	35				

In western Belize at Central Farm in the last decade a small decrease in the mean compared to the first two decades was observed. A small decrease in the amount of precipitation during the months of August and September has occurred and a noticeable

increase in November (Figure 6.15). The ANOVA analysis however showed that there was also no significant difference between periods $F = 0.08$, $p = 0.93$ (Table 6.4).

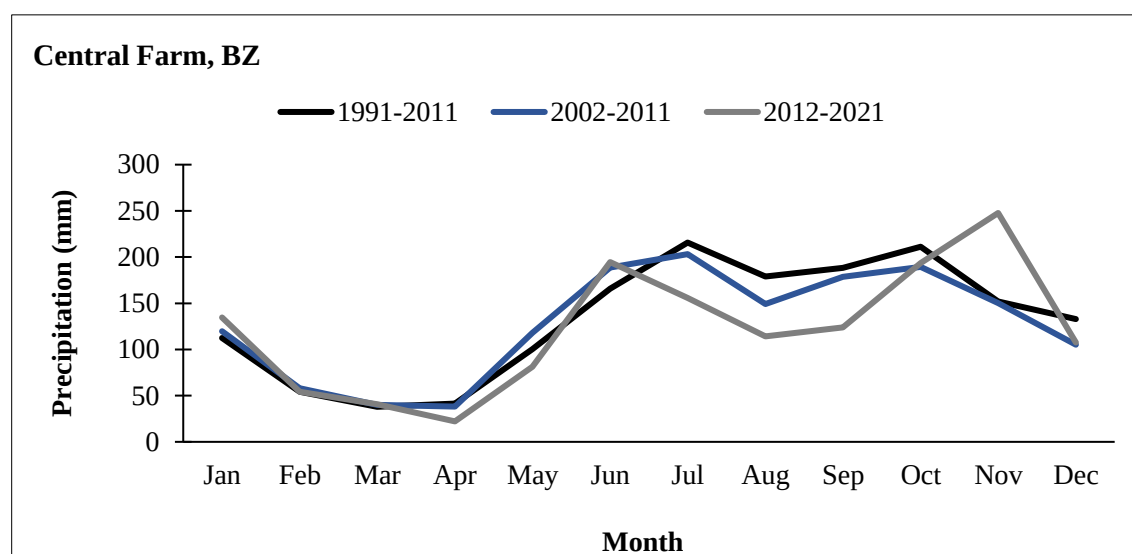


Figure 7.15. Average monthly precipitation (mm) for Central Farm station for the period 1991-2011, 2002-2011 and 2012-2021.

Table 7.4. Descriptive statistics and ANOVA analysis of monthly average precipitation (mm) between the periods 1991-2011, 2002-2011 and 2012-2021 in Central Farm, Western Belize.

SUMMARY							
		1991-2011		2002-2011		2012-2021	
Mean		132.58		128.15		122.49	
Median		142.32		134.39		119.11	
Standard Error		18.40		16.96		19.56	
Standard Deviation		63.74		58.74		67.77	
Range		177.70		165.00		225.54	
Minimum		37.96		38.17		22.15	
Maximum		215.66		203.17		247.69	
ANOVA							
Source of Variation	SS	df	MS	F	P-value	F crit	
Between Groups	613.83	2	306.92	0.08	0.93	3.28	
Within Groups	133164.82	33	4035.30				
Total	133778.65	35					

In northern Belize, in Libertad, the last decade shows a small decrease in average monthly precipitation from May to August, but an increase has occurred in October, November and December has occurred (Figure 6.16). The ANOVA analysis however showed that there was also no significant difference between periods $F = 0.03$, $p = 0.97$ (Table 6.5).

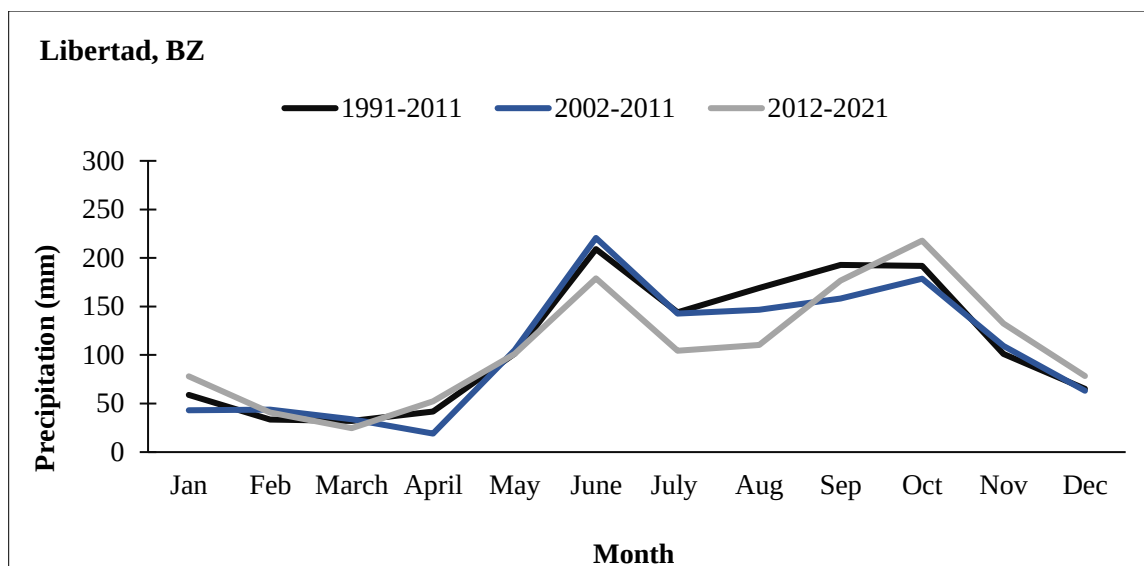


Figure 7.16. Average monthly precipitation (mm) for Libertad station for the period 1991-2011, 2002-2011 and 2012-2021.

Table 7.5. Descriptive statistics and ANOVA analysis of monthly average precipitation (mm) between the periods 1991-2011, 2002-2011 and 2012-2021 in Libertad, Northern Belize.

SUMMARY						
	1991-2011		2002-2011		2012-2021	
Mean	111.72		105.31		107.98	
Standard Error	19.33		18.78		17.15	
Median	101.19		107.11		102.75	
Standard Deviation	66.97		65.07		59.40	
Range	177.03		201.54		193.19	
Minimum	32.08		19.07		24.65	
Maximum	209.11		220.61		217.84	
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	249.08	2	124.54	0.03	0.97	3.28
Within Groups	134723.12	33	4082.52			
Total	134972.20	35				

6.3.4. Precipitation Anomalies

6.3.4.1 Peto, Yucatan, Mexico

Annual precipitation anomalies for Peto station (Figure 6.17) revealed that over the last 30 years variable positive and negative extreme changes have occurred in the area. In the last two decades (2000-2021) there has been an increase in positive anomalies compared to the 1990's, with eight large positive anomalies recorded, the largest in 2020 with a value of 36.27 mm which aligns with one of the years with a high incidence of hurricanes and tropical storms. In contrast negative anomalies have been variable in the first two decades but less common in the last decade. This increase in positive anomalies have been reflected in an increasing trend of rainfall (See Fig. 6.11)

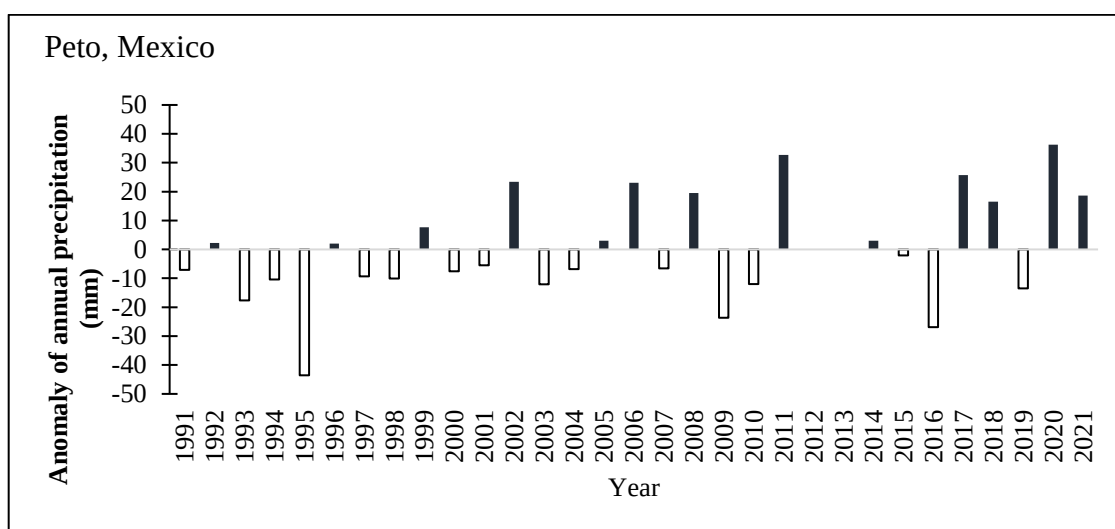


Figure 7.17. Rainfall anomaly analysis for Peto in southern Yucatan, Mexico, from 1991-2021.

6.3.4.2. Central Farm, Western Belize

When analysing the precipitation anomalies for the station in Central Farm (Figure 6.18), it was noticed that a lot of variability has occurred in the area, with extreme positive and negative events both occurring. The most remarkable anomaly portrayed in the analysis correspond to that of 2019, considered as one of the worst and prolonged droughts experienced in the country (Caribbean Development Bank, 2019). Central Farm has experienced more fluctuations in rainfall with a larger number of negative anomalies reflected a declining trend in rainfall (See Figure 6.12).

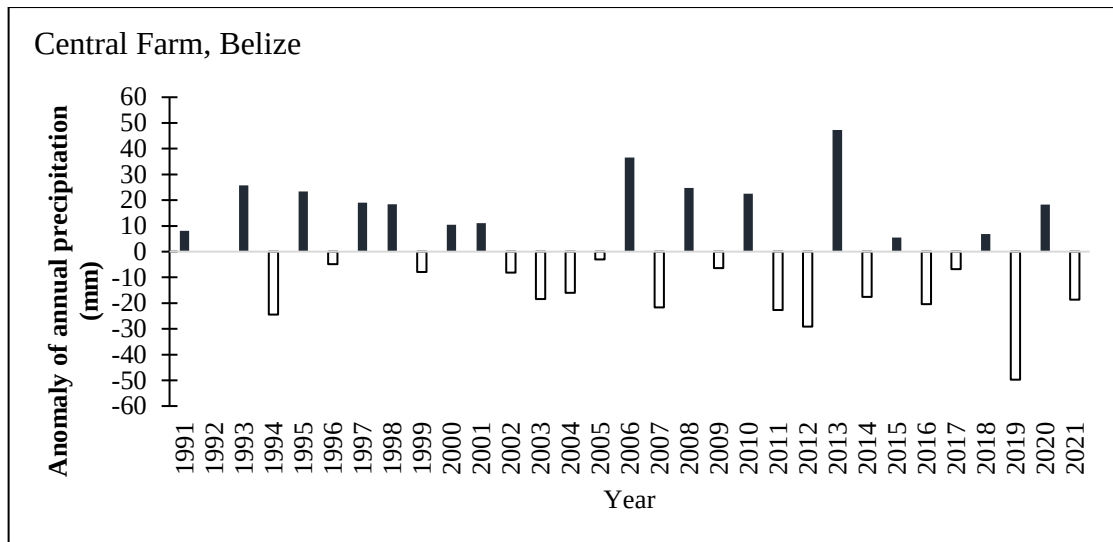


Figure 7.18. Rainfall anomaly analysis for Central Farm in western Belize from 1991-2021.

6.3.4.3. Libertad, Northern Belize

Rainfall anomalies for Libertad station revealed a roughly equal number of positive and negative anomalies. However, in the first two decades a larger number of positive anomalies were observed compared to the negative anomalies; in contrast in the last decade larger and constant negative anomalies have been observed compared to the positive ones although an exceptional positive anomaly was recorded in 2013 (Figure 6.19). Larger and constant negative anomalies reflected a decreasing trend in rainfall (See Figure 6.13) and the highest from the three studied stations.

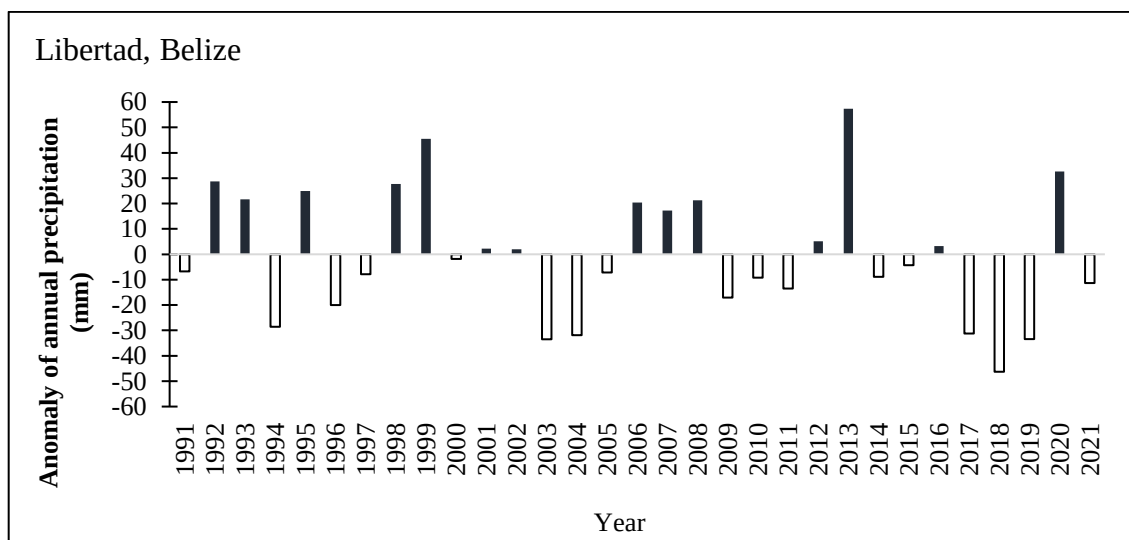


Figure 7.19. Rainfall anomaly analysis for Libertad, northern Belize from 1991-2021.

6.4. Changes in Temperature

No temperature data were available for Libertad in Northern Belize. In relation to changes in temperature in Peto, Mexico the average temperature in the past 30 years was higher ($M = 27.3\text{ }^{\circ}\text{C}$, $SD=0.64$) than in Central-Farm ($M = 26.43$, $SD = 0.37$). A two-tailed t-test for independent samples (equal variances not assumed) showed that the difference between Peto-AvgTemp ($^{\circ}\text{C}$) and Central-Farm AvgTemp ($^{\circ}\text{C}$) was statistically significant, $t(45.07) = 6.58$, $p = <.001$, 95% confidence interval $[0.63, 1.18]$. In both stations results showed a small but increasing trend. Trends showed that southern Yucatan (Peto) presents the highest coefficient of increase ($0.02\text{ }^{\circ}\text{C}/\text{year}$) while western Belize (Central Farm) presents a coefficient of increase of $0.01\text{ }^{\circ}\text{C}/\text{year}$ (Figure 6.20 and 6.21).

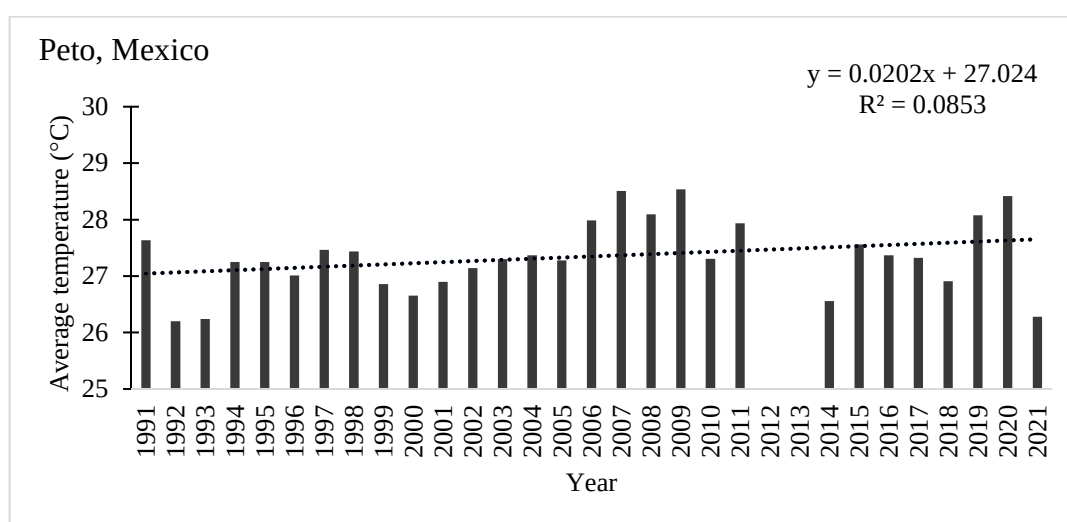


Figure 7.20. Mean annual temperature ($^{\circ}\text{C}$) for Peto in southern Yucatan (1991-2021)

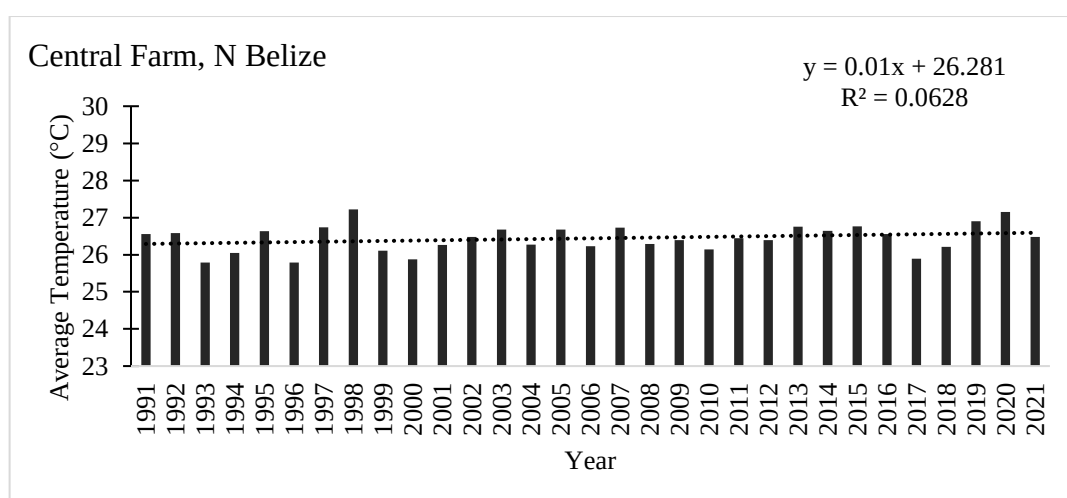


Figure 7.21. Mean annual temperature ($^{\circ}\text{C}$) for Central Farm in western Belize (1991-2021)

6.4.1. Temperature anomalies

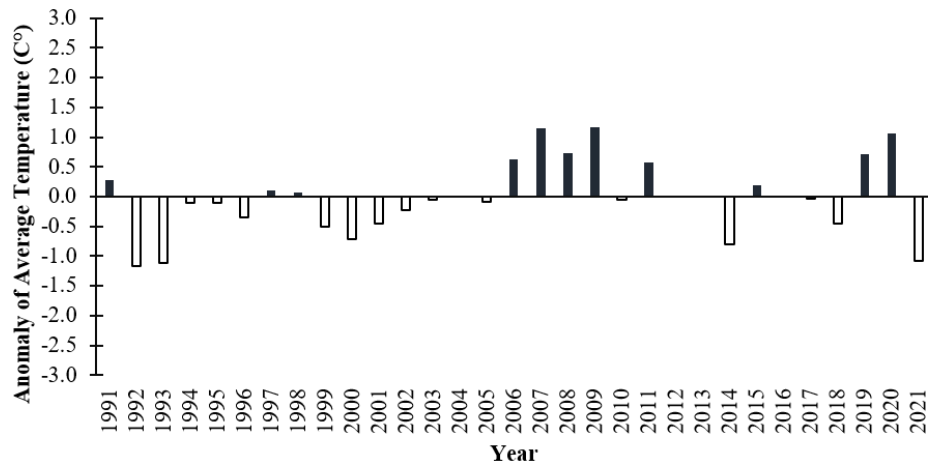
6.4.1.1. Peto, Yucatan, Mexico

Anomalies of average, maximum and minimum temperature were also analysed (Figure 6.22) which showed that average temperature has been more variable since 2006, with a clear increase in positive anomalies (Figure 6.22a). This from negative to positive anomalies reflected an increasing trend for average temperature (See Figure 6.20). When looking separately at maximum (Figure 6.22b) and minimum temperatures, the latter showed a highest incidence of negative anomalies from 2004 (Figure 6.22c); while maximum temperature showed a highest incidence of positive anomalies since 2006 and has remained variable with rises of 1.0 and 2.0 C° between 2006 and 2011 then decreasing and increasing again in 2019 and 2020 (1.0 and 1.1 C° respectively).

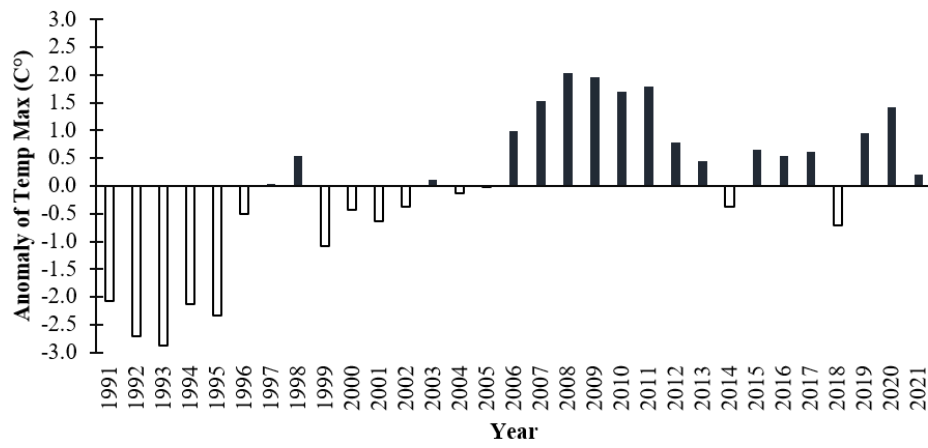
6.4.1.2. Central Farm, Western Belize

In the last decade (the timeframe farmers perceived as when weather conditions started changing) average temperature anomalies in Central Farm station have been a combination of positive and negative anomalies across time with some years showing little variability from the normal mean (Figure 6.23a) and no evident changes in the trend for average temperature (See Fig. 6.21) . In the last 3 years however, maximum temperature anomalies have presented a higher amount of variability, with 2019 recording the highest max temperature anomaly (aligning to when the prolonged drought occurred) in the last two decades with increasing records of 1.4 degrees above from the average and surpassing the highest record of increase from 1998 which was of 1.1 degrees (Figure 6.23b and 6.23c).

Peto, Yucatan (a)



Peto, Yucatan (b)



Peto, Yucatan (c)

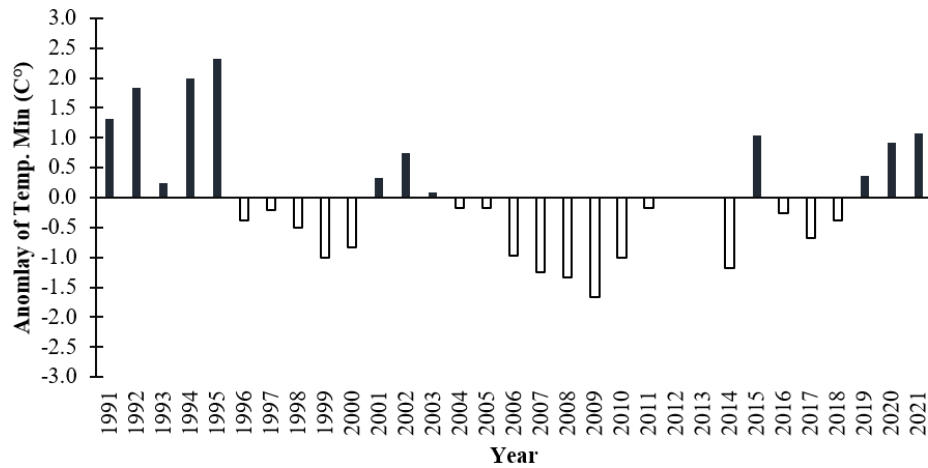
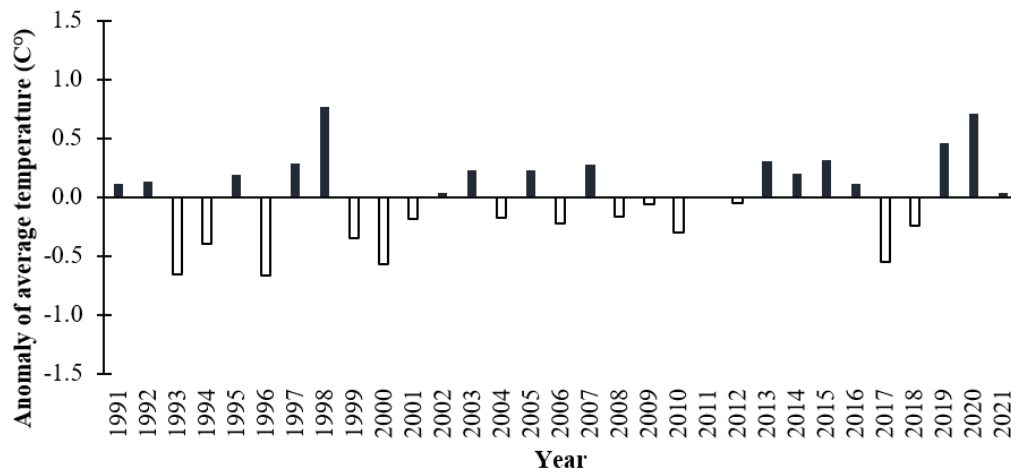
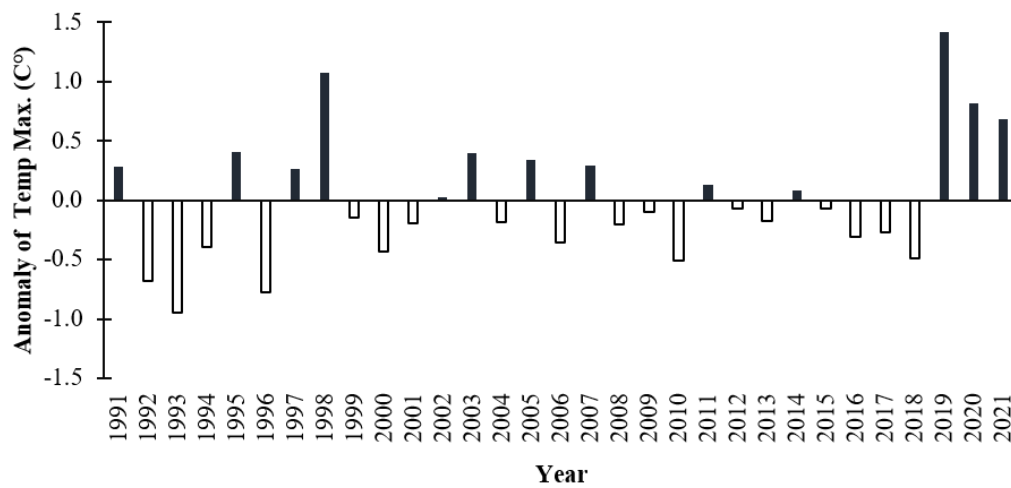


Figure 7.22. Annual average temperature (a), maximum (b) and minimum (c) temperature anomalies for Peto, southern Yucatan, Mexico from 1991-2021.

Central Farm, Belize (a)



Central Farm, Belize (b)



Central Farm, Belize (c)

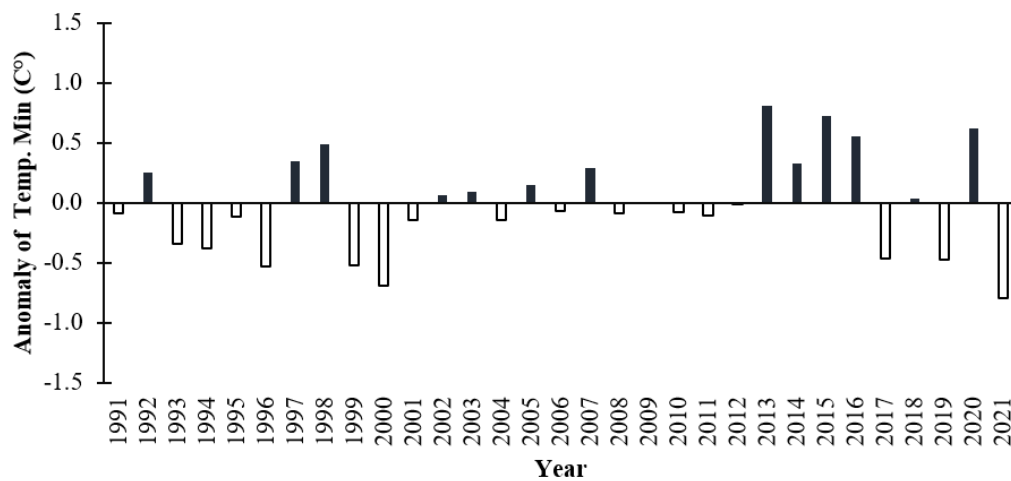


Figure 7.23. Annual average temperature (a), maximum (b) and minimum (c) temperature anomaly for Central Farm, western Belize from 1991-2021.

6.5. Linking farmers views about climate change with meteorological data in Maya Yucatec Communities in Mexico and Belize.

6.5.1. Farmer's beliefs about climate change

Individual past experiences with severe weather events can influence perceptions of present and future climate risks and can also influence adaptation action (Woodmansee et al. 2021). Adaptation can also be informed by beliefs and people's knowledge around the causes of climate change has been proven to be a driver of deciding whether to act or not (Azadi et al., 2019).

The majority (94%) of the farmers that took part in the survey in Yucatan and Belize (Chapter 3; Section 3.7.1.1) reported that they have noticed changes in the climate. Most of the farmers surveyed were males (83%) and only 17% were females, with ages ranging between 30 and 80 years old. Farmers had different years of farming experience, between 1-10 years (3%), 11-20 years (9%), 20-30 years (14%) and more than 30 years (71%), the other 3% didn't provide information.

Results from the surveys indicated that Maya Yucatec farmers believe that climate change is caused mainly by anthropogenic activities (human-induced causes) such as pollution (36%) deforestation (18%), overpopulation (4%) and use of chemicals (4%). This is particularly important because previous work has argued that farmers who believe that climate change is attributed to anthropogenic activities are more likely to engage in adaptation strategies to protect their farms from future impacts (Arbuckle et al., 2013b). However, the present research also reported, as the third main cause of climate change, a shared belief that it was a result of farmer's activities and they held some responsibility for it (13%). Other causes mentioned included supernatural causes (God's will; 4%) and natural causes (2%), while 9% could not explain what is causing it (Figure 6.24; Madhuri & Sharma, 2020).

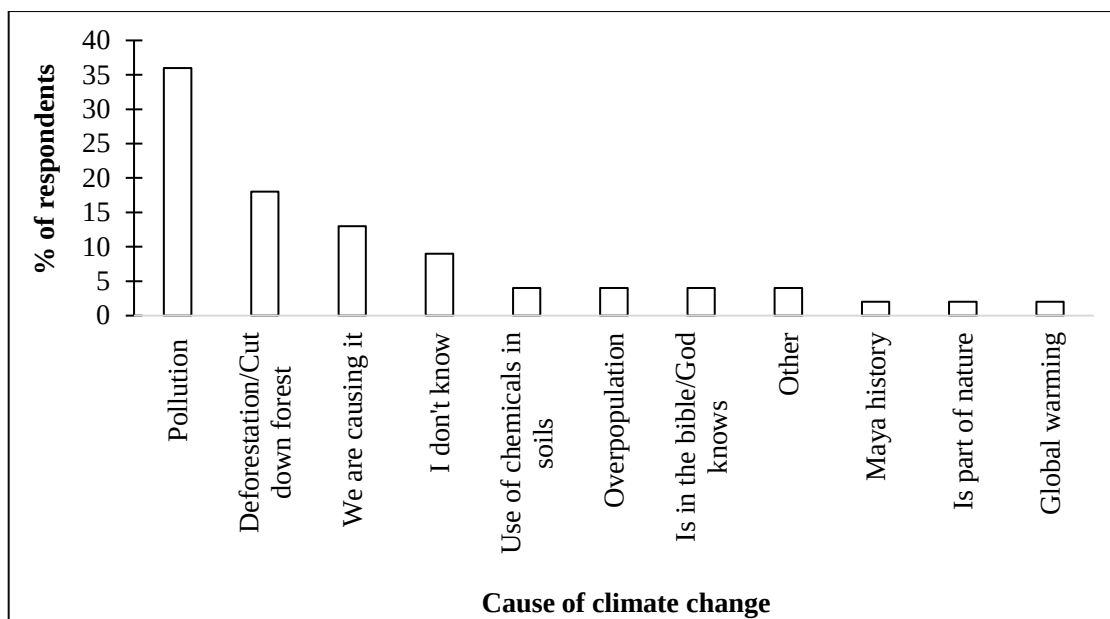


Figure 7.24. Causes of changes in climate according to Maya Yucatec farmers in Mexico and Belize based on a survey conducted in 2021 (N=35).

Testimonials collected from case studies (Chapter 3) in both Mexico and Belize aligned with the results obtained in the surveys in relation to a shared perception that anthropogenic activities have been the main causes of climate change.

“Because of the people who are using a lot of smoke, chemicals, the factories. Because people are cutting down the forest.”

Farm 5, San Antonio, Belize, 2021

“Well, they say that people cut the mountain (the forest) a lot, they are cutting it down, so it doesn't rain so often anymore, humans are destroying it.”

Farm 7, San Jose Succotz, Belize, 2021

“Well, it may be due to contamination or I think it would be for those reasons. I also think it is because there are also people who have already forgotten where we are, we are not alone, there have always been beings who also help. We ask the lords of the mountain, the lords of the rain to help us to have good rains to have a good harvest. So sometimes I think that because people are modernizing, they think of other things and they don't follow up on these beliefs, so I think that there is something that also affects it.”

Farm 4, Xoy, Yucatan, 2021

Testimonials also highlighted the belief that farmers are highly responsible for climate change.

“It has been altered and we have altered it, and in general, well, in many ways we have contaminated it through the abuse of the use of certain chemicals, the abuse of certain products, the lack of maintenance of certain cleanliness and hygiene, more than anything, the contamination has influenced a lot in that and we have been somewhat irresponsible.”

Farm 2, Oxkintok, Yucatan, 2021

“One of the problems that has caused us to have this climate and why it is going crazy is modern agriculture. Because as I mentioned to you, if before we only cultivated two acres, now we cultivate perhaps up to five times more than before. And what does that mean? If you look around now almost everything is clean there are almost no bushes (trees) and from my point of view, I believe that this is one of the biggest problems that we are facing now through what we are practicing now, using modern system compared to traditional. I believe that this is one of the reasons that is affecting the climate.”

Farm 8, Patchakan, Belize, 2021

Given that there was a shared belief about the causes of climate change, particularly a level of personal responsibility, this was a potential sign of the influence that external sources might play on farmers' beliefs. To gather more information around this, farmers were also asked about their main source of information related to climate change which they indicated was the result of lived experiences (years of farming/knowing the land), but also acquired when getting informed about climate change support programmes or attending specific events related to climate change (Weber, 2010).

Findings from the surveys indicated that 57% of all the farmers have never been invited to an event related to climate change, while 43% have been invited but only 34% attended vs 9% that did not. When analysed by country, in Belize 71% have never been invited to a climate change event, the other 29% have been invited and all have attended. In Mexico, 56% have been invited but from this only 39% has attended. The main topics covered according to those attending was i) What is climate change, ii) Causes of climate change, iii) Impacts and Adaptation strategies, iv) Conservation and sustainable agriculture practices and management and v) Preparation of organic inputs (biofertilizers). According to information provided by farmers these events were provided by government institutions (*Sembrando Vida* Government Programme in Mexico, MoA and DoE in Belize), a local non-government organisation (NGO; Friends for Conservation in Belize) and other institutions, however some farmers couldn't remember which institution was in charge.

Although most of the Maya Yucatec farmers surveyed in Belize have never been invited to a climate change event, about 47% of them get informed about climate change aid programmes through the extension officers when visiting their plots, 19% of them through neighbours and family, 5% through radio another 19% do not get informed at all, and the 10% left did not answer or did not specify (Figure 56). On the other hand, farmers surveyed in Mexico indicated that about 24% got informed about climate change support and programmes mostly through neighbours and family, 22% by radio and 19% by community meetings. Other means to get informed in Mexico included television (10%), internet (5%), collaboration with research institutes (5%), visits from extension officers from agricultural programmes they are part of like Sembrando Vida (5%) and 12% do not get informed (Figure 6.25).

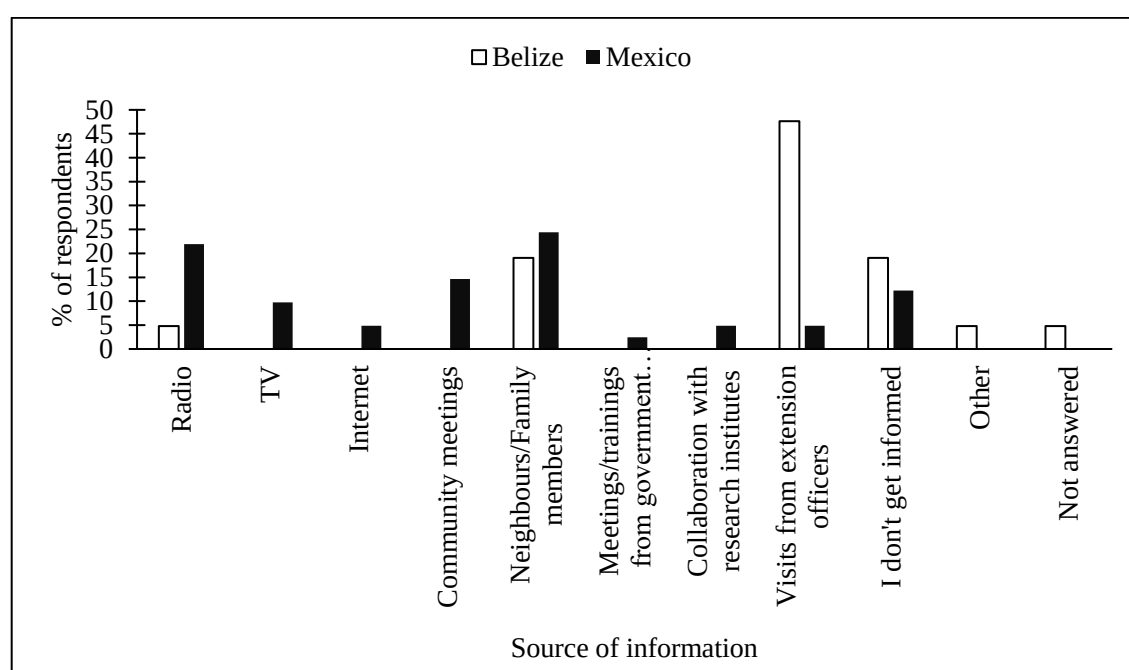


Figure 7.25. Sources of information around climate change aid programme amongst Maya Yucatec farmers in Mexico and Belize. (MX-N=18; BZ-N=17).

Within the case studies, six out of eight farmers across Mexico and Belize had been, or are somehow involved or affiliated to external organizations or agricultural programmes, but depending on the programme some have been more exposed to climate change information than others. However, most of farmer's testimonials provided evidence that being part of an agricultural programme or collaboration doesn't necessarily guarantee access to climate change information but can shape beliefs around it when accessed.

[Research Institution]

“With Cimmyt last year (2020) there were some workshops that they gave in Quintana Roo and they invited us to find out how much climate change affects us and all that and well, I explained to them what has been happening for a long time from late 1980s early 1990s and how everything changed and well, that's the workshops where there was an opportunity to comment.”

Farm 4, Xoy, Yucatan, 2021

[Sembrando Vida Programme, Mexico]

“Not in that sense. Not on that topic, we have received training on other topics but climate change so far no.”

Farm 2, Oxkintok, Yucatan, 2021

[Ministry of Agriculture Belize]

“Yes, I've attended, but it's been several years since we went to that [climate change training], but until now I don't think they've done another one, and they haven't let us know, it's been years. “

Farm 7, San Jose Succotz, Belize, 2021

[Cooperatives/Groups]

“No (never invited) and yes (involved). Let me explain. As I mentioned with this carrot production group, we had some guests from the weather forecasting [Met Service]. They promised us that they will have more communication and they will send more frequent information”.

Farm 8, Patchakan, Belize, 2021

“I am in a cooperative, they [Ministry of Agriculture] notify me and I notify the members [about the training], and they come and if we accept we hold a meeting and farmer's go, whoever wants to go can go but whoever does not want to go or not interested, don't.”

Farm 5, San Antonio, Belize, 2021

In order to better understand the overall drivers of decision-making and adaptation processes it was also important to learn about how and what Maya Yucatec farmers perceive as change in climate and how this compared with the analysis of meteorological records.

6.5.2. Perception of climate change and weather variability by Maya Yucatec farmers in Mexico and Belize

In relation to farmers' perception of changes in climate, although many of the farmers couldn't recall which events had impacted them the most, in both countries specific ranges of time were mentioned when changes in weather started. Around 25% of the farmers indicated that changes started 10 years ago, followed by 17% farmers who believed that changes began between two and four years ago and 11 % believed that four to six years ago (Figure 6.26). This accounted for almost 50% of all the surveyed. The other 50% surveyed had very divided perceptions in terms of timespan. Around 29% mentioned ranges from 15 years ago or more, to 40 years ago or even longer, while 11% mentioned ranges from one to nine years ago and 6% didn't provide any answer.

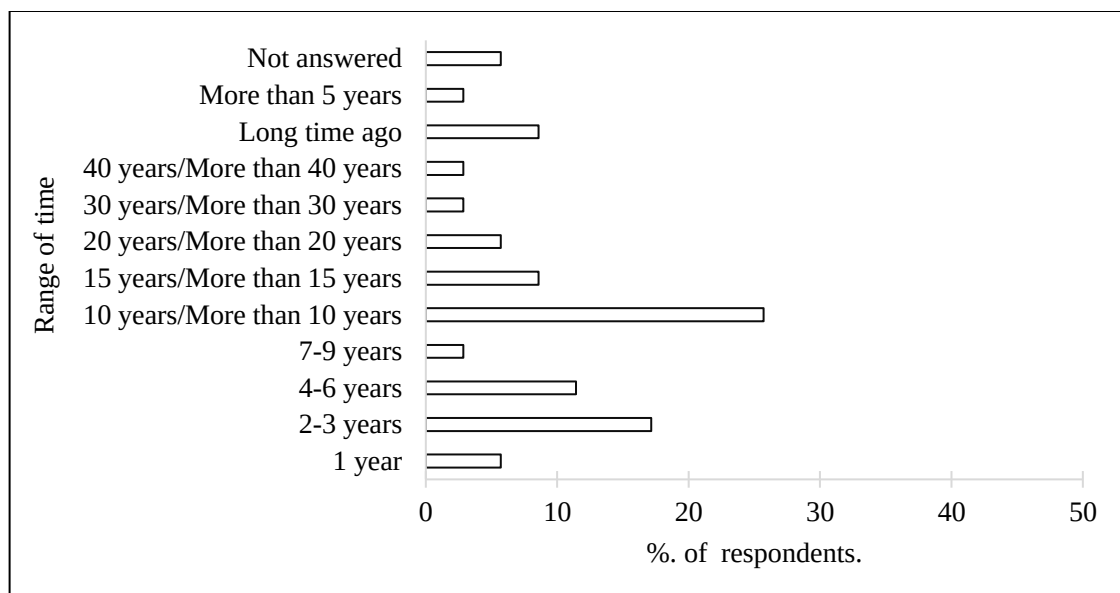


Figure 7.26. Range of time of when changes in climate started to occur in the study areas in Mexico and Belize. (N=35).

Temperature and precipitation variability were the two main changes detected by farmers (Figure 6.27). Overall, the most frequently perceived change identified by Maya Yucatec farmers in Belize was higher temperature (increase of temperature), while in Mexico it was higher temperature and more variable rainfall.

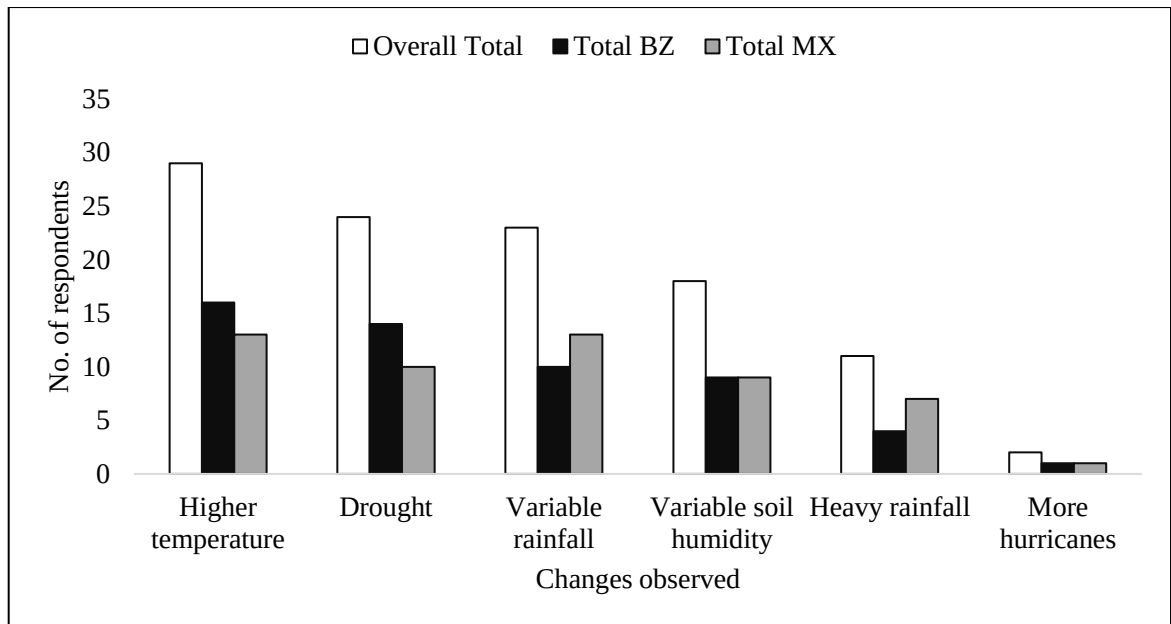


Figure 7.27. Changes in weather perceived by Maya Yucatec Farmers in Mexico and Belize (N=35).

6.5.2.1. Perception of changes in climate in Belize

When analysing these perceptions at the community level per country, perceptions varied between communities (Figure 6.28).

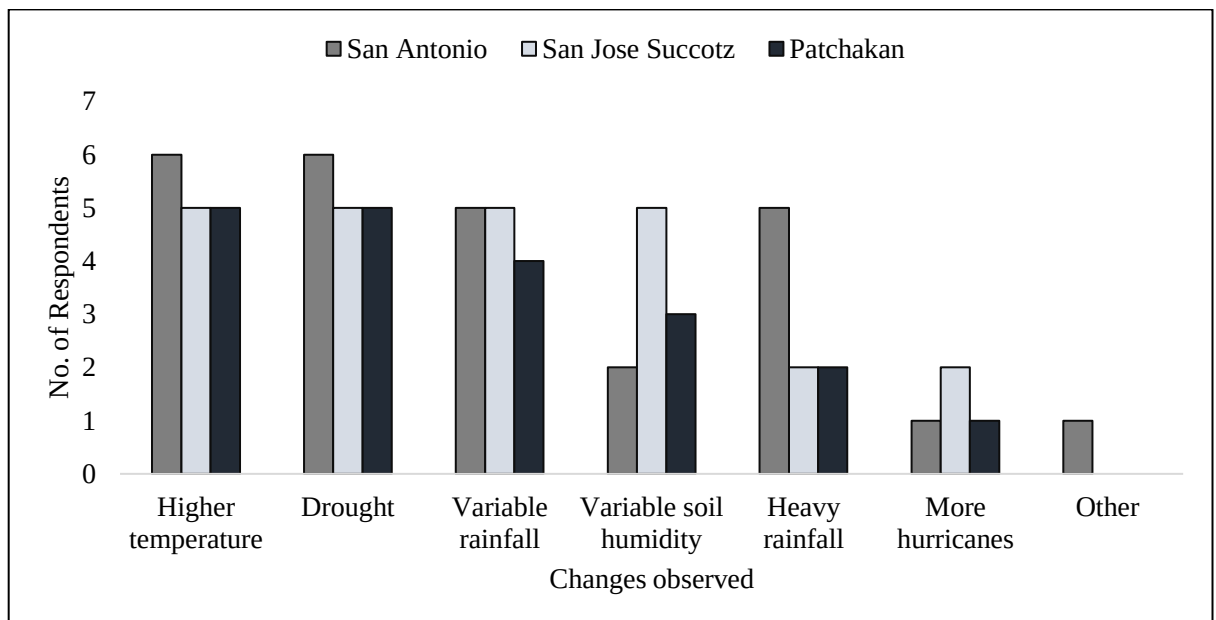


Figure 7.28. Changes in weather perceived by Maya Yucatec Farmers in three Maya communities in Belize.

In western Belize within San Antonio (Chapter 3), higher temperature and drought were the main and equally perceived changes commencing three to ten years ago. In San Jose

Succotz perceptions were more diversified, since high temperatures, drought, variable rainfall and variable soil humidity were equally perceived changes commencing between one and ten years ago. When comparing these perceptions with the meteorological data, farmers' perceptions appear to align with the records in the study areas in relation to rainfall variability but not necessarily with temperature. Central Farm station recorded a decrease in rainfall in the last decade and since 2002 more negative anomalies (See Fig. 6.18) which have been accurately perceived by farmers. In relation to perception of higher temperature although average temperature hasn't really increased in this area (See Fig. 6.21), reports showed that maximum temperature anomalies have presented a higher amount of variability (including that of 2019; See Fig. 6.23) which is what farmers have perceived.

During participant observation and interviews with farmers who took part in the case studies within the communities of San Antonio and San Jose Succotz (21km from the meteorological station at Central Farm) a shared perception that climate is becoming more variable in relation to the onset of the rainy season and that precipitation late in the year was increasing was stated. As a result, they have now been able to have two harvests (compared with traditional one). This was particularly important for the farmer doing monocropping under a rainfed system and for farmers cultivating vegetables.

“Right now, this [harvest] ends in November. In December we began to sow to harvest in February. Now, in December it is raining. Right now [September] the hurricane season has started, so the soil is kept moist and then it is planted.”

Farm 7, San Jose Succotz, Belize, 2021

Farmers testimonials both during surveys and interviews highlighted an increase of rainfall variability with a higher incidence of droughts or erratic rainfall. These perceived fluctuations were portrayed in the precipitation anomalies for Libertad with equal number of positive and negative anomalies but a large negative anomaly in 2018 (See Fig. 6.19) and a decreasing trend for annual rainfall (see Fig. 6.13). In Central Farm similar as in Libertad, high rainfall variability has occurred with a combination of both positive and negative anomalies but only a very large anomaly, that from the drought of 2019 (Figure 6.18). Farmers during surveys made remarks about the impact of the 2019 drought which was also confirmed by farmers during participant observation who provided additional testimonials about how rain used to be more frequent in the past in both San Antonio and San Jose Succotz.

“Before the rains weren't that scarce, they were frequent...before, the rains began like in August and now they take a month, two months. Late. We cannot sow, because we sow when the first rain falls.”

Farm 7, San Jose Succotz, Belize 2021

“Belize's problem is the drought; it takes the longest. Before it rained all the time. Now, is rare when it rains.”

Farm 5, San Antonio, Belize 2021

“In my father's time it rained on time or it dried out on time. There was more rain than now. Not now, it's already different, quite changed. When I was young there were no farms like now. There were more trees, more trees and just a few houses. San Antonio was not populated as it is today, there were maybe 20 families, maybe. Few families and all around, just mountains, big trees over here, you can't imagine how vast. It was even scary to go down there because it's dark, because they were so big. I think that there was more rain at that time, because the weather was cooler. But right now, just dry. Just farms and there are no trees, there is no humidity, is drier and the soil becomes drier and it takes time to rain.”

Farm 6, San Antonio, 2021

In northern Belize in Patchakan, higher temperature and drought was perceived as changing equally, however perceptions of when these changes began were divided. Fifty percent of farmers had a perception that changes began ten years ago or more, while the other fifty believe they began between two and six years ago. A common perception shared amongst farmers was related to the extreme drought experienced in 2019 similarly perceived by farmers in western Belize (San Antonio and San Jose Succotz) and which was portrayed in the anomaly's analysis (Section 6.3.4.2)

Another “anomaly” mentioned during participant observation and surveys by farmers and shown within the rainfall anomaly analysis for Libertad Station was in relation to how 2020 was a “wet year” and perceived as a good year given that allowed for better yields considering that 2017, 2018 and 2019 had the largest negative anomalies in the area (See Fig. 6.19) . This beneficial perception contrasted with that expressed by farmers in Xoy for the same year given that during October 2020 the Yucatan State was impacted by three tropical storms: Gamma, Delta, and Eta after already been impacted by Cristobal tropical storm in June 2020.

Despite not having data available for temperature for Libertad a testimonial from a farmer in northern Belize who took part in the case study pointed out some of the changes in temperature perceived in the area across time.

“Before, the climate was different. At times it rained a lot like this, but the verano (dry season) was not as strong as now. So even though we had a strong verano then, it wasn't that strong compared to what it is right now. We always sowed and the maize will always come out and we would always get a good harvest; but now these days we cannot say this, we can no longer predict the weather. In the past although the sun was strong, we always had a good harvest.”

Farm 8, Patchakan, Belize, 2021

6.5.2.2. Perception of changes in climate in Mexico

In southern Yucatan, Mexico in Xoy the main perceived change was rainfall variability and for the most part farmers believe that changes began between 15 and 30 years ago (Figure 60). This perception mirrors the results of the rainfall anomalies which portrays an increase of rainfall variability over the last two decades (2000-2021; Section 6.3.4) although this has been towards an increase of rainfall positive anomalies. In Tzucacab perceptions were more diversified since higher temperatures, drought and variable soil humidity were perceived as equal and farmers have a perception that changes began ten years ago or in the “long time ago” range. In western Yucatan State (Mexico) in Maxcanu, higher temperatures, variable rainfall and heavy rainfall were equally perceived changes (Figure 6.29) and most of the farmers perceived changes began between 10 and 15 years ago.

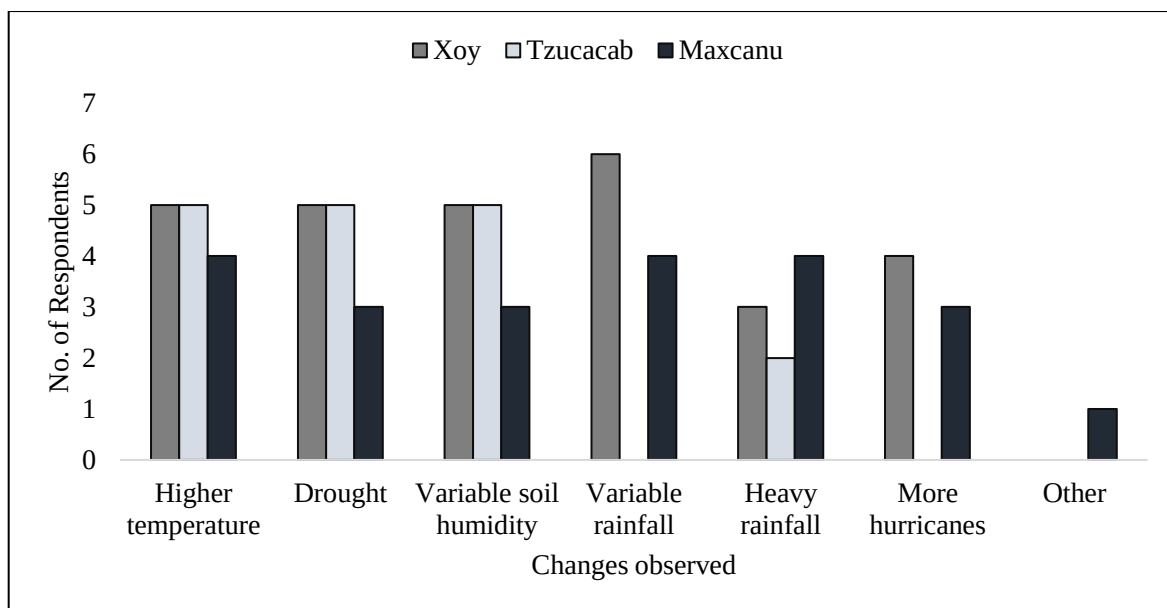


Figure 7.29. Changes in weather perceived by Maya Farmers in three Maya communities in Mexico.

When looking at the perceived changes by community and the information obtained from meteorological data for Peto (5 km from Xoy), a testimonial from the case study in Xoy (Farm 4) regarding changes in climate in the community pointed out an opposed perception from the climate analysis (which portrayed an increase in rainfall; See Fig 6.11 and Fig 6.17):

“I think that now climate change is affecting us a lot, climate change due to erratic rains. Previously for May for June and for the milpa, I remember that I started working at the end of the 1980s, the rains have been very good, regular rains, but since the year 2000 everything has changed. There have been many changes that, well, it doesn't rain, it doesn't rain, it doesn't rain, although the planting season for May has arrived, June is when we sow seasonal crops, but it no longer rains.”

Farm 4, Xoy, Yucatan, 2021

6.6 Impacts of climate change on *milpa* system and adaptation strategies implemented in agricultural plots in Mexico and Belize

6.6.1. Impacts

The climate analysis revealed that persistent rainfall variability and rainfall anomalies have occurred in the study areas and have been perceived by farmers that live there. As a result of changes in climate, farmers in Mexico and Belize have experienced different impacts in their farms (Figure 6.30). According to the survey conducted the main impact in both countries has been crop loss. In Belize, 88% percent of the respondents considered

that this has been the major impact, followed by constraints on land management (76%) and more (plant) diseases (76%). In Mexico 89% percent of the respondents also considered crop loss as the main impact, followed by land management constraints (78%) and reduced yield (78%). Compared to Belize only 39% of the farmers in Mexico considered more diseases as an impact. In both countries changes in soil were also considered an impact by 59% of farmers in Belize, but only by 39% in Mexico.

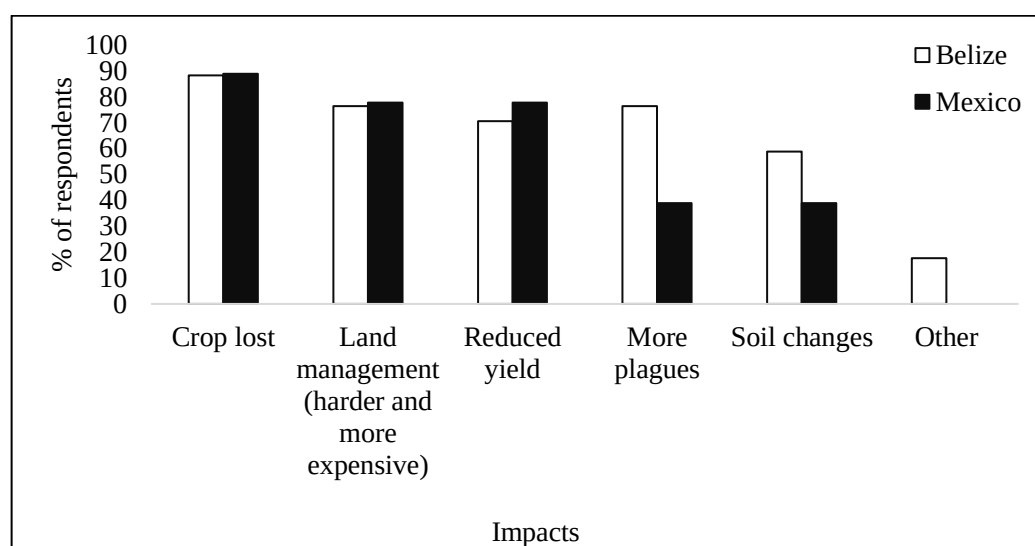


Figure 7.30. Impacts of climate change in *milpas* system in Mexico and Belize according to surveys conducted in 2021 (N=35).

Farmers who took part in the case study analysis gave testimonial of the impacts of climate change which aligned with findings from the survey

[Expensive and Hard Land Management]

“You must invest extra money to buy other kinds of irrigation, when you could invest it in other things... Right now, we have a problem, before it rained more often, now as nature stops, the water stops, the plants do not want to grow, sometimes they die, and what lives takes time and we have to add fertilizer”

Farm 7-HY, San Jose Succotz, Belize 2021

[Diseases and changes in Soil]

“[Climate change] Brings more plague. Even more with weather like today, the sun warms up, tomorrow it rains, it can rain like right now for two hours, from time to time, then the sun rises again and that sun kind of parboils the soil. It cooks it. It is a virus that reverses it to earth. This is how the plague comes forming it until the soil catches it.”

Farm 5-HY, San Antonio, Belize 2021

“When I started here, I can tell you I was a nobody, what I was looking for per week was to cover my expenses. So, I started looking for the chile (pepper) and I planted a mecate and it gave me a lot without using any kind of liquids without using anything. So, about 5 or 6 years after planting it, I had up to half a hectare, but when the pests began to increase? and all that, I couldn't do it anymore. And then I had to invest more for it to produce. There weren't so many bugs and pests... That's what has damaged the agriculture a lot [the pests], that's what has impacted me because I can't plant anymore...I didn't need so much of that [pesticides].”*

**land area measure referred to in milpa agriculture equivalent to 20mx20m=400m²*

Farm 3-LNXY, Tzucacab, Mexico, 2021

[Reduced Yield]

“Well, it has affected me in the sense that sometimes a crop is expected on certain dates and I don't get it on that date, I have it later or I get it in a minimal way and well, that has repercussions because I have planned in a certain way how much I should get and I don't get it and that's where it affects me the most.”

Farm 2-LM, Maxcanu/Oxkintok, Mexico, 2021

[Crop loss]

“The greatest impact is when you see that your little plants are green at the beginning and begin to turn yellow. So much sun, no water, nothing. The rain comes very little, because sometimes is in October when it comes right now, July, August, September has already passed and no rain... Working is not difficult at all, the difficult thing is when you have already planted and wait for the rain to come, but there is no rain. So, the problem is that the maize does not come out, so you have to go back to spray and sow again.”

Farm 1-HST, Maxcanu/Oxkintok, Mexico, 2021

“Climate change affects us because rain does not fall at 100%, it does not fall when we think it will and when planting season arrives, it is too late. At the time of planting, well, the challenges are the rainy season because, for example, if it doesn't rain by May, June then by July, August, planting is overdue, the planting season is temporary, so the challenges are that there are risks that even if you get to plant, the animals take it out, then it is something difficult. And well, when the hurricane season arrives it is another difficult challenge because it is something that cannot be controlled. For us, milpa is random because you never know if you are going to produce or if you are going to achieve a good harvest because you sow and you don't know if it is going to rain, or if it is going to be dry or if hurricanes are going to arrive. So, they are difficult challenges that we don't know how each cycle will work.”

Farm 4-LGR, Xoy, Mexico, 2021

Farmers were further questioned about additional impacts on agriculture besides changes in climate. Overall, the main ones were pests/diseases (21%), marketing (21%), problems with management/yield (12%) and money/finance (7%). Other impacts, with less than 5% of respondents, included weeds, Covid-19, lack of support from government and age. However, when looking at it separately by country, impacts in Belize are mostly related with marketing (lack of opportunities to commercialize), unfair prices and too much local competition, whereas in Mexico most impacts are related with pests or diseases (Figure 6.31).

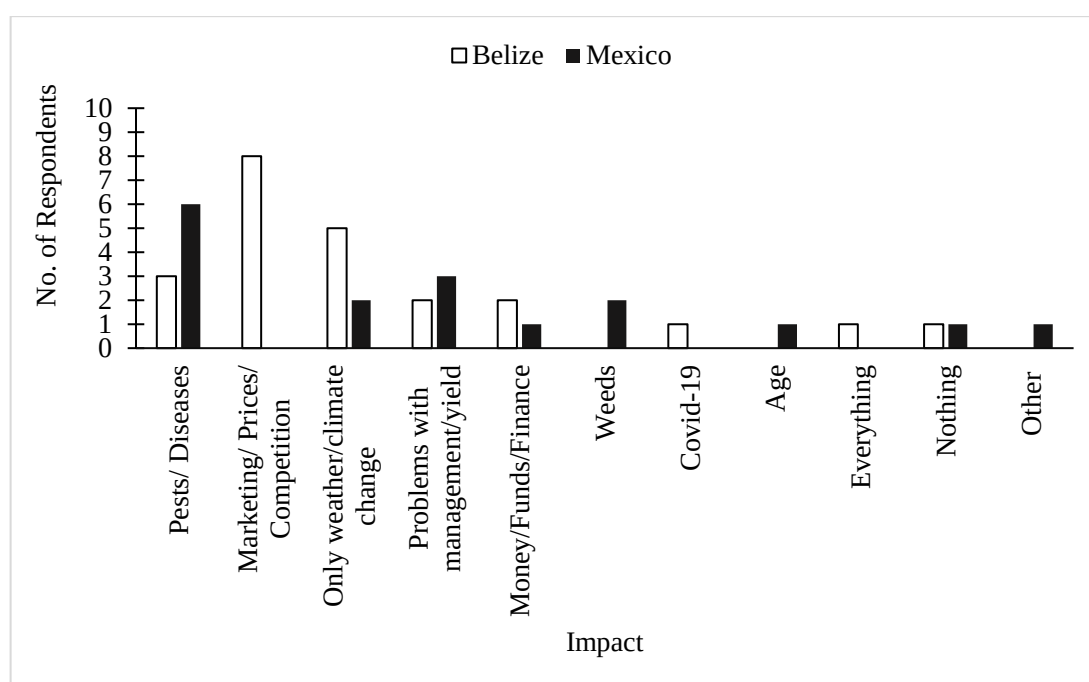


Figure 7.31. Additional impacts perceived by farmers within the *milpa* system in addition to climate change in Mexico and Belize. (N=35).

6.6.2. Adaptation Strategies

As a result of climate change impacts, Maya Yucatec farmers in Mexico and Belize have put in place a series of adaptation strategies. According to the surveys, the main strategy adopted and considered useful and reliable according to farmers, is changing or adjusting planting dates particularly for maize, however more farmers in Mexico use this strategy (27%) compared to Belize (15%; Figure 6.32). Farmers highlighted that this is the most reliable strategy since, it is implemented based on long term direct observations and experiential learning of local weather conditions, but also because is cost-effective and productive.

Both countries have also adopted and implemented other adaptation strategies (Figure 6.32). The five main strategies farmers in Belize have implemented are the following: i) use different varieties and crops (11%), ii) use more water irrigation (11%), iii) increased use of herbicides (10%), iv) use crop rotation more often (10%) and v) reduce land cultivation (10%). In Mexico, however, farmers have preference for the following strategies: i) Increase use of herbicides, fungicides, pesticides and fertilizers (16%), ii) use crop rotation more often (11%), iii) use different varieties and crops (9%), iv) use new techniques to improve soil fertility (9%) and v) look for new water irrigation techniques (9%).

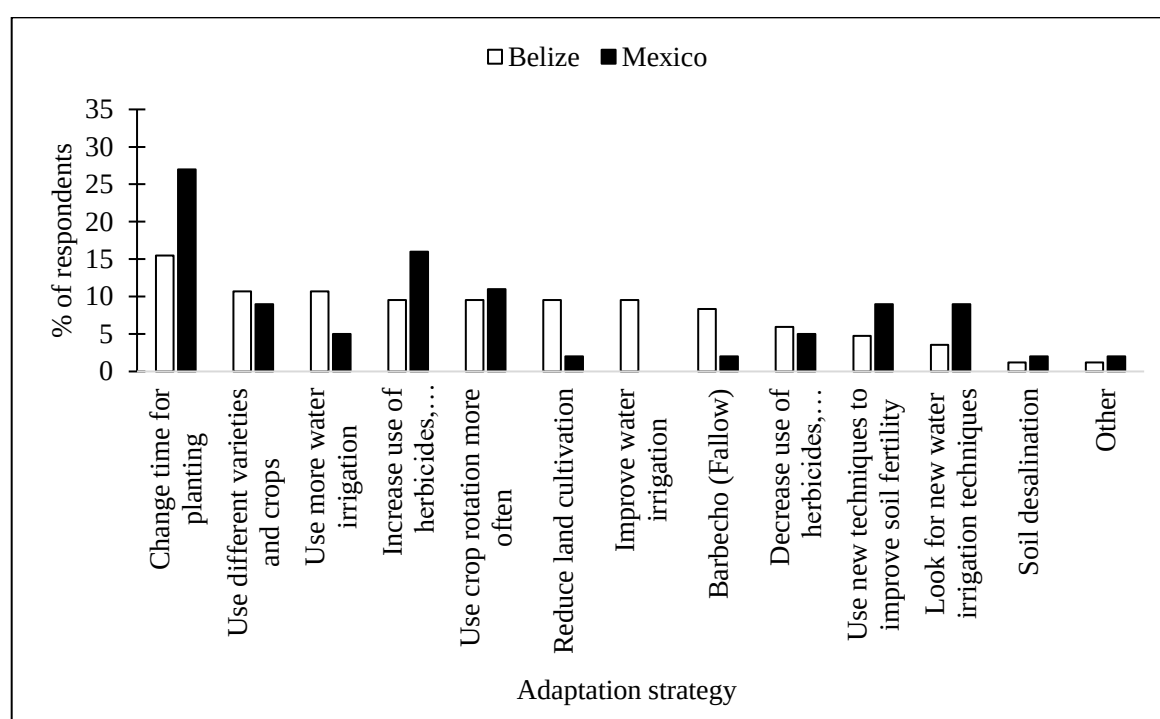


Figure 7.32. Strategies implemented in Mexico and Belize to minimize the impacts of climate change in *milpa* systems based on surveys conducted in September 2021 (N=35).

Farmers who took part in the case studies also mentioned different strategies implemented as a result of drought and erratic rainfall. These were like those mentioned in the surveys. In the case of farmers in Mexico these strategies included the following: use more fertilizer (Farm 1), delay the planting season (Farm 2), use chemicals and stopping planting certain crops, diversification of activities (e.g. beekeeping; Farm 3), organic seed cure (e.g. covering the seed with extract from neem plant) and use chemicals if necessary (Farm 4), mulch around the plant stems to conserve more humidity (Farm

4). In Belize farmers' strategies included the following 1) cover crops, ploughing and irrigation (Farmer 5); 2) irrigation (Farm 6); 3) chemical seed cure (Farm 7) and improve irrigation system (Farm 8).

In 2023, during the workshops conducted in both countries, farmers from the study areas were invited to a joint session where they had the opportunity to exchange knowledge with fellow farmers from other communities in relation to soil characteristics (See Chapter 5; section 5.5), to climate change impacts and farming adaptation strategies. The results of these workshops allowed an assessment of the impact of climate change on farmer's lives to be undertaken, as well as rating the effectiveness of strategies implemented. Given that some farmers have little formal education, an adapted 5-point scale (Figure 6.33) was used to rank the impacts of climate change and effectiveness of strategies in a creative way. This adapted guide used to assess effectiveness was developed guided by actual responses obtained on surveys and semi-structure interviews which allowed farmers to be familiar with the scale points and encourage participation (Figure 6.33).

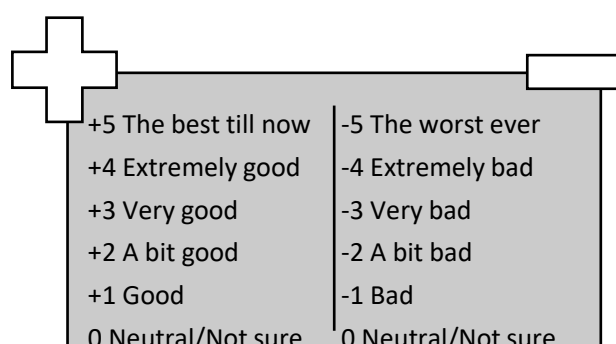


Figure 7.33. Adapted 5-point scale to rank changes in climate and effectiveness of strategies based on farmer's perceptions.

Using the guide mentioned above and supported by field assistants, farmers identified different types of impacts and wrote them on cards which were further ranked based on their perception of how good or bad have impacted their farming systems (Figure 6.34). Once this was completed a similar process was followed to assess strategies implemented and its effectiveness.



Figure 7.34. A farmer from Xoy, Mexico naming and ranking impacts experienced, and effectiveness strategies implemented in his *milpa* plot.

In terms of impacts, results aligned for the most part with what was found in the surveys. In both countries, farmers indicated that drought has been the greatest impact, ranking the impact between a bit bad (-2) and the worst ever (-5). In addition to drought, events such as hurricanes, pests and rainfall variability were also mentioned in Mexico, whereas in Belize heavy rainfall, flooding and extreme dry season were also identified as impactful (Figure 6.35).

WORST				NEUTRAL			BEST			
-5	-4	-3	-2	-1	0	1	2	3	4	5
	Drought	Drought	Drought							
	Hurricanes	Pests (animals such as armyworms, badgers and birds) Lack of rainfall	Hurricanes Pests Erratic rainfall Increase in use of chemicals							
Drought	Drought									
Flooding (Due to heavy rainfall)	Heavy rainfall									
Extreme dry season										
Farmers in Belize	Farmers in Mexico									

Figure 7.35. Events considered as having impacted farmers the most as a result of climate change and rated according to the level of impact in their farms.

In terms of adaptation strategies these differed from those mentioned during the surveys in the case of Mexico but were very similar to those mentioned by farmers in Belize. A total of 27 strategies were mentioned by farmers in both countries which were later classified into: a) land management practices, b) technological developments, c) agricultural inputs practices, d) seed and crop management, e) soil management and f) market and finance practices (adapted from Smit & Skinner, 2002; see Table 6.6).

In terms of implementation, farmers in Belize appeared to have put in place more strategies when compared to Mexico, however there were divided opinions about the effectiveness of such strategies. This could be because agriculture in Belize is now more diversified between plots and evaluation of effectiveness is more complex and for the most part farm-specific depending on the type of crops planted. In Mexico, despite having mentioned fewer strategies implemented, the level of effectiveness was more consistent and rated between extremely effective (+5) and effective (+3; Table 6.6).

In terms of effectiveness, strategies mentioned during the Mexico workshop showed that using more biofertilizers has been effective to minimize the impact of climate change, however this differed from the survey results which showed an increase in the use of chemicals. Strategies mentioned by farmers at the workshop in Mexico fell into two categories i) land management and ii) agricultural input practices. The main ones were as follows: a) reducing chemicals, b) increased use biofertilizers and c) reduced planting areas. In Belize strategies mentioned fell into all the categories, however technological developments, soil management and market finance practices were clearly dominant over other categories. Common strategies used in both countries fell into the agricultural input practices category and included a) decreased use of chemicals (due to high costs) and b) use biofertilizers/organic fertilizers.

The strategies mentioned by farmers also provided evidence about the type of knowledge prioritised when implementing these strategies. Strategies were classified as follows: a) adaptation driven by farmers' knowledge/experiential learning (AD-FK) and b) adaptation driven by government or non-government organizations (AD-GNG). Eighteen of the strategies implemented are driven by external sources and only nine driven by farmers' knowledge. From those eighteen driven by external sources, thirteen have been implemented in Belize and only three in Mexico and two implemented in both countries.

In contrast out of the nine strategies driven by farmer's knowledge, five have been implemented in Mexico and four in Belize (Table 6.6).

Table 7.6. Strategies implemented by farmers in Mexico and Belize to minimize the impacts of climate change in *milpa* system and level of effectiveness based on farmers' experience. (Mexico=MX; Belize=BZ; Adaptation driven by government or non-government organizations=ADGNG; Adaptation driven by farmer's knowledge=AD-FK).

Adaptation strategy	Country	Knowledge	Effectiveness
Land Management			
Reducing planting area	MX	AD-FK	+2, +3, +4
Adjust/ delay planting calendar	BZ	AD-FK	+5
Not cutting down high monte	MX	AD-FK	+2
Take advantage of first rains	MX	AD-FK	+3
Crop Rotation	BZ	AD-FK	+2, +5
Not burning	MX	AD-GNG	+2
Use brush cutter	MX	AD-GNG	+2
Leave the mulch	MX	AD-FK	+2
Planting strategy	BZ	AD-GNG	+2, +4
Technological Developments			
Invest in irrigation systems	BZ	AD-GNG	+5
Try new irrigation systems	BZ	AD-GNG	+5
Use of solar panels for irrigation system	BZ	AD-GNG	+5
Dig deeper wells	BZ	AD-FK	+4
Greenhouse	BZ	AD-GNG	+4
Seeds and Crops Management			
Use local seeds	MX	AD-FK	+4
Change to hybrid corn	BZ	AD-GNG	+4
Use new varieties (maize and vegetables)	BZ	AD-GNG	+5
Agricultural inputs Practices			
Use more pest control	BZ	AD-GNG	-5, 0, +3, +2, +4
Use less chemicals (fertilizers)	MX	AD-GNG	+2, +4, +5
	BZ	AD-GNG	-5
Use more chemicals (fertilizers)	BZ	AD-GNG	-4, -3, +4, +5
Use biofertilizers/more organic	MX	AD-GNG	+2, +4, +5
	BZ	AD-GNG	0, +4
Preparations for pest control	MX	AD-GNG	+2
Soil management			
Soil nutrition	BZ	AD-GNG	+2
Beds	BZ	AD-GNG	-3

Drainage system	BZ	AD-GNG	+2
Marketing and Financial Practices			
Change marketing strategy (direct sale)	BZ	AD-FK	+5
Financial Support	BZ	AD-GNG	-5

6.6.3. Use of indigenous knowledge in traditional Maya Yucatec livelihoods and impact of climate change on traditions and cultural beliefs used in agriculture.

Evidence collected in this study suggests that amongst Maya Yucatec farmers in Mexico and Belize indigenous knowledge is still used in many activities in their daily life other than agriculture (Figure 6.36). In Belize people continue to rely on indigenous knowledge in activities such as health, cutting wood, weather forecasting, gardening and cooking. While in Mexico it is still widely used in family gatherings, cutting wood, health, cooking and weather forecasting.

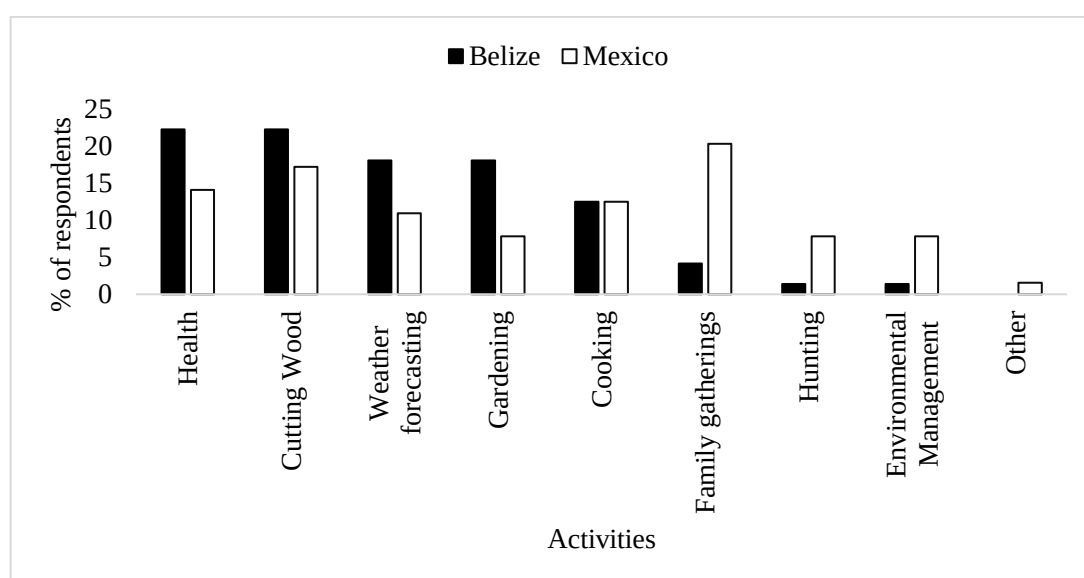


Figure 7.36. List of activities practiced by Maya Yucatec farmers in Mexico and Belize that depend on indigenous knowledge (N=35).

As expressed by farmers in both countries, indigenous knowledge is still used for weather forecasting; however, there was a shared perception that specific rituals and traditional practices are impacted by climate change and a reason why they will no longer be practiced in the near future. The perception is that climatic changes have affected the traditional way farmers plant because the rain no longer falls at the usual time, as they traditionally have learnt it. As a result, farmers have been forced to adapt their planting calendar. This has further implications such as directly impacting rituals and traditional

practices and, consequently, also has a negative effect on the processes of transmission of this knowledge. Testimonials in both countries provided examples of how indigenous knowledge has been impacted by climate change in different ways and the consequences of it:

“Cabañuelas [traditional annual weather forecasting] cannot be trusted anymore. At first there was about a 90% that you can trust that on a certain date it will rain or in a certain day it will be a period of drought but now with climate changes there is no guarantee that it is true that certain day it will rain. Now there is no such guarantee, there are changes I would say a little drastic because there is no such confidence on this system.”

Farm 4, Xoy, Yucatan, 2021

“There are more plagues [diseases] so I can't use these beliefs anymore because they don't work.”

Farm 5, San Antonio, Belize, 2021

“Yes, [climate change] in a certain way has affected traditions and knowledge. Because sometimes we have heard of acid rain and traditionally, we were instilled in or told that it was a way for the plants to not produce what was expected. Today we have realized that there are certain things that were not traditionally believed to be but were due to certain other factors that are related to the climate.”

Farm 2, Maxcanu/Oxkintok, Yucatan, 2021

Well, almost not anymore traditions are practiced. There are moments, for example, they say that so much rain is because there was a change. It's the cabañuelas [annual weather forecasting] that they say have something to do with the sun, and this one, well, they say that it is what has brought a lot of rain. There are also occasions when the rain stops, and the tremendous drought comes. Here the ancients already knew that May was the time they should plant. Now no longer, [it is] June, July, August depending on how the rain comes but no more.

Farm 1, Maxcanu/Oxkintok, Yucatan, 2021

Right now, the traditional practices have worked, but sometimes not because nature changes in different ways, sometimes it rains, sometimes there is sun, when it should rain there is sun, and when nobody waits for the water, it falls there.

Farm 7, San Jose Succotz, Belize, 2021

Well, one of the biggest problems and what we defend and try to study, since the Mayan culture still led in my generation, we observe a lot of the changes in weather. This have affected us a lot because we go from one extreme to the other in years like when summer is very strong. That especially prevents us from sowing native varieties which cannot be planted at any time because I was taught, they are sown at specific times. Now we have reached the point of losing our native seeds because of that [changes in weather], these are the varieties of seeds that we keep every year to sow the next year.

Farm 8, Patchakan, Belize, 2021

6.7. Climate change and knowledge systems: A reflection for traditional agriculture in Mexico and Belize.

6.7.1. Differences and similarities between farmers' perceptions around climate change.

Overall, farmers in Mexico perceived that changes in climate began longer ago than those in Belize. This perception is of interest since it has been argued in the literature that in affect-based processing when learning by personal experience about climate change, people tend to follow a learning process based on recent events rather than distant ones (Weber, 2010). This however doesn't appear to be the case given the percentage of farmers that mentioned 10 years or more (65%) as a range of time of when changes in climate began compared to shorter ranges of time (28%). Studies conducted with farmers in Africa, Asia and Central America have shown a range of between 10 and 20 years when changes in climate began, a similar time scale perceived by Maya Yucatec farmers in Mexico and Belize (Fosu-Mensah et al., 2012; Madhuri & Sharma, 2020; Viguera et al., 2019). Particularly, the results aligned with a recent systematic review conducted by Madhuri and Sharma (2020) in which the author found that out of 162 papers published between 2000 and 2019 the timescale of 10 years from when the farmers perceive changes started is stated in 22 studies, while 20 years is mentioned in 36 studies and 30 years is mentioned in 21 studies.

In relation to the causes of climate change, results from the research indicated that in both countries there is a shared perception that anthropogenic activities have been the main cause of climate change. These results align with those found in surveys conducted with farmers in Saudi Arabia (Azeem and Alhafi Alotaibi, 2023). Although beliefs around the main causes of climate change have been mostly acquired from farmers' lived experiences, a shared belief around anthropogenic activities including farmers' own actions as the main cause and holding responsibility for it (see 6.5.1) suggests that in the

study areas Maya Yucatec farmers' beliefs also appeared to be socially constructed by their social networks through their role in farming groups, community group interactions and institutional engagements (Wens, 2021). This has distinctly and indirectly shaped their climate change consciousness (Petrescu-Mag et al., 2022).

In the case of Belize awareness of climate change has been significantly influenced by formal and informal informative processes from the extension service and in the case of Mexico by social ties nested in neighbours and family, most likely involved in some sort of agricultural programme or collaboration and through local radio which (based on participant observation) is a common means of getting information on a daily basis. These results also provided evidence of how new information is acquired within a specific ethnic group and how varied this process can be. Subsequently, this may have had potential implications on how Maya Yucatec farmers act and make decisions, but also on the way knowledge is used to overcome climate change impacts.

6.7.2. Farmer's perception of climate variability and scientific data

Results from comparing farmers' perceptions with the meteorological recorded data indicates that Maya Yucatec farmers in Mexico and Belize (with a few exceptions) are for the most part experienced about climate variability in the study areas, but have also noticed long-term changes in weather patterns and extreme events (e.g. changes in rainfall onset/patterns, seasonal variability over time, drought, increase of maximum temperatures; Madhuri and Sharma, 2020).

Farmer's perceptions aligned in most cases with scientific data in relation to precipitation variability. In Belize, similar shared perceptions across the three communities indicates that remarkable changes on monthly rainfall patterns during the winter months has allowed farmers to implement new management strategies like growing short varieties and other varieties that could adjust to new climate patterns. This intuitive perception of changes around winter rainfall patterns was shown through the monthly rainfall analysis highlighting that from November through January rainfall has increased in both northern and western Belize (Section 6.3.3.). Similarly, in Mexico during participant observation and surveys different farmers pointed out how significantly wet 2020 was compared to many other years in the last decade, which together with Covid-19 highly impacted their crops. This perception was portrayed in the anomaly analysis which in fact highlighted

that 2020 year has undoubtedly been one of wettest years in the last decade yet not as wet as 2013 (Section 6.3.4).

In the case where farmer's perception was different to that from the climate data analysis, two assumptions can be made. The first one is that given that microclimates in Yucatan can vary significantly within short distances in the case of Peto the distance of the nearest meteorological station (5km from the community) and the geographical features surrounding the community (forested compared to the semi-urban where Peto station is located) could influence the local conditions as reported by farmers, stating that the majority of times the local forecast would not align with the local conditions experienced.

The second assumption is that the testimonial from farmers, like that from Farm 4 in Xoy (See 6.5.2.2) is portraying a perception based on a consistent pattern that the farmer has been exposed to in the long-term. In the past he was exposed to more regular and frequent amounts of rainfall across months that are relevant for each of the *milpa*'s development stages. In the last decades however, rainfall variability has become more frequent giving the impression that is raining less when in fact it has increased annually. As a result, changes are altering monthly rainfall amounts, since in the last decade the driest months have become even drier, the beginning of the rainy season has become wetter while important months that used to be wetter such as September are now becoming drier and subsequent months often associated to harvest are now becoming wetter compared to past decades.

Although it's true that farmers' perceptions somehow aligned with scientific records, this does not necessarily indicate whether farmers understand the difference between climate variability and climate change and should be identified in future research questions to get a better insight about it. Some evidence can be seen when comparing farmers' perception of higher temperature with climate data analysis. Information available in western Belize (Central Farm) showed that there hasn't been a significant increase in average temperature in the past 30 years, but rather variability between positive and negative anomalies. Similarly, some recent increase in positive anomalies for maximum temperature in the past three years combined with a large negative anomaly in precipitation in 2019 could have induced the perception of higher temperature. Having examined this, it is evident that there is a need for in-country collaborators to focus on developing accessible tools and training capacity that allow for farmers to be able to

easily differentiate climate variability from climate change, while also exploring further this differentiation and the implications of this in future research.

6.7.3. Differences and similarities in climate change adaptive capacity in Maya Yucatec agricultural systems

Results of this study provided evidence that there are cross-national differences in climate change adaptive capacity. The adaptation strategies implemented by Maya farmers in Mexico are collectively similar and inclined towards land use changes and land management based on their own knowledge, experiential learning and long-term common cultural beliefs which also appears to be a mechanism used to make sure indigenous knowledge is transmitted. In contrast, in Belize, most of the adaptation strategies are farm-specific and inclined towards technological improvements (e.g. greenhouses, water irrigation), soil management and market and finance practices embedded on knowledge acquired from external sources. Indigenous knowledge however if used in Belize is as a farmer quoted still “*very important, and like a saving for emergencies*”.

Results showed that the majority of Maya Yucatec farmers in the study areas who have experienced some type of climate variability, despite a high interaction with external sources and institutions, have put in place one common adaptation strategy influenced by their own knowledge (adjusting farming calendar; Mogomotsi et al., 2020; see 6.6.2). The adoption of this strategy aligns with findings elsewhere in Yucatan (Mardero et al., 2015; Metcalfe et al., 2020) and in Central America (Harvey et al., 2018) but also contributes to the argument from Celio et al. (2014), that cost and effectiveness can influence farmer’s behaviour toward adapting certain practices. Although this was an important similarity found across countries there is a remarkable difference in how *milpa* agriculture is practiced between Mexico and Belize influenced by the interaction between internal factors and external sources thus shaping most of their other adaptation strategies that can allow them to fulfil their farming priorities.

Belizean Yucatec farmers although still relying on experiential knowledge to make decisions, the type of strategies adopted showed a higher influence of institutions over their climate change awareness and adaptive capacity compared to those in Mexico. This influence has indirectly enhanced or undermined other aspects associated with *milpa* in Belize such as knowledge systems, local governance, social structures and their

relationship/attachment to *monte* (See Chapter 4; Section 4.1.1). In particular, Belizean Yucatec farmers have had a (historical) consistent relationship with the government (currently with the extension service) giving them access to other types of knowledge (knowledge sharing), that although beneficial, has indirectly shaped their ways of perceiving *milpa*, their priorities and choices of adaptation strategies. Their adaptive capacity has been reshaped by formal and informal social networks built on social capital (Pelling & High, 2005; Wang et al., 2021) which are considered important in terms of building resilience (Rockenbach and Sakdapolrak, 2017). Social and institutional trust might also play a part on their risk perception and consequently their adaptive capacity. In this case their level of individual trust in government discourses (extension service; Appleby-Arnold et al., 2018) can also be a driver of which specific strategies to implement.

In contrast, farmers in Mexico, although there is involvement with external sources, this relationship is not consistent and only certain knowledge accessed through these sources is considered to minimize the impact of perceived risks. Social networks and social trust in the study areas in Mexico have also played a role in their adaptive capacity, but the nature of these social networks is different from that in Belize. Social trust is inclined more towards interpersonal trust, nested in social or community groups formed by family or neighbours rather than institutional trust (Wang et al., 2021). Also, social values, norms and worldviews play an additional role given that in the study areas in Mexico they have stronger cultural and spiritual ties with the *monte*/forest (See Chapter 4; Section 4.1) and are under communal land tenure (*ejido*). As a result, their adaptive capacity is shaped by social networks, but is culturally specific and relies mostly on their own knowledge systems.

Overall, adaptation strategies mentioned by farmers who took part in the case study analysis and the surveys are like those reported by farmers in Ethiopia (Belay et al., 2017), Egypt (Kassem et al., 2019), Central America (Harvey et al., 2018) and South Africa (Gbetibouo, 2011). In Mexico, some discrepancies were observed when comparing responses from surveys and interviews with those obtained during the workshop in relation to soil management. A potential explanation for this could be that during the workshops there were attendants who belonged to the government agricultural programme *Sembrando Vida* who are strictly forbidden to use chemical fertilizers, so it

is possible that the presence of external members within the workshop may have influenced the responses compared to the surveys which were anonymous.

Findings from this study showed that it appears that adaptation strategies are not enough to cope with the impacts of climate change in each country and not very effective since farmers continue to struggle every year with yields; however based on their narratives and assessments it can be assumed that the ones in place have somehow helped farmers to sustain their site-specific priorities against perceived risks such as food and financial insecurity, climate change or Covid-19. Similar findings have been reported in forest-dependent indigenous communities in Botswana (Rahman and Alam, 2016) and other natural resource-dependent communities. The results also indicated that independently of sharing the same ethnicity (Maya Yucatec) and being familiar with similar indigenous knowledge, this does not determine their adaptive capacity but rather the influence of site-specific drivers such as social networks, social values and norms and their own perception and worldviews of local environmental conditions (Wang et al., 2021).

6.7.4. The process of knowledge change in Maya Yucatec farming systems in the face of climate change and other challenges.

Evidence from this study suggests that indigenous knowledge systems can be eroded because of exposure to external factors (e.g. market integration; western science through development programmes and technological knowledge) which can lead to loss of indigenous language and changes in perceptions and worldviews from the local conditions (e.g. the *monte*). However in the study areas, this exposure is not necessarily decreasing or eroding all forms of indigenous ecological knowledge, instead it has shaped the acquisition of new ecological knowledge (Guest, 2002) due to a new exposure to unfamiliar situations and risks (e.g. climate change and Covid-19) outside of what is commonly known within their social-ecological settings.

Farmers in both countries indicated that overall, in the face of challenges, indigenous knowledge and traditions are still widely used to overcome such challenges. Within this research 57% of all interviews expressed that they use indigenous knowledge and traditions during challenging times, 34% indicated that they don't use it anymore, 3% indicated that sometimes and 6 % didn't answer. This study was conducted during Covid-19 and 46% of farmers indicated that they were using indigenous knowledge and traditions to protect themselves against Covid-19, mainly based on ethnobotanical

knowledge. Testimonials from farmers who took part on the study also indicated that as a result of Covid-19 farmers had to rely on ancient techniques and indigenous knowledge to continue managing their farms given the increased cost of agricultural inputs.

The *milpa* system in Mexico and Belize has undoubtedly been adapted across time, however across countries the adaptation process has been shaped by different site-specific internal and external factors (Kodirekkala, 2017), but also based on farmer's individual perception of risk during challenging times and their own farming priorities.

In Belize, the traditional *milpa* system has been reshaped due to strong discourses oriented to capitalise agriculture as a business which continue to influence many of their contemporary trading systems (See Chapter 4; Section 4.2). As a result, farmers started decreasing and replacing the use of a traditional *milpa* system (and the indigenous knowledge associated) for a more diversified vegetable cultivation which required new forms of knowledge and practices different from those traditionally learnt. Although this shift in agriculture was influenced by external factors, internal limitations experienced by farmers in traditional *milpa* including the hard work, how time consuming it was, low yields, low income and lack of interest from younger generations also played a role (Kodirekkala, 2017).

Milpa was then adapted from a self-sufficiency system to a market dependent system that could provide both financial and food security benefits, thus re-shaping the main priorities of Maya Yucatec farmers in Belize. With the adoption of this agricultural approach, the indigenous knowledge embedded in traditional *milpa*, started to be abandoned and new practices and knowledge were adopted which are appropriate to new local environmental and socio-economic conditions focused on market and business survival (Kuehne, 2014); but resulting in a disruption of the ways of traditionally transmitting indigenous knowledge. However, with challenges such as climate change and Covid-19 which has continuously and increasingly threatened key elements (e.g. environmental conditions) that help them achieve their dominant priorities (market and food security), farmers have been required to use their own knowledge or produce new knowledge based on their continued interactions and observations of their local world in order to reduce future risks and minimize the impacts (Kodirekkala, 2017). Farmers' adaptation process in the face of challenges has been reactive and responsive but planned

short-term and tactical in terms of temporal scope (Table 42;(Smit et al., 1999) which could put at risk the long term-sustainability of local agriculture.

In contrast, although farmers in Mexico have been also exposed to external sources (e.g CIMMYT, Sembrando Vida Government Programme) and some market integration, farmers priorities are focused on food security, indigenous knowledge, worldviews (relationship with the *monte*), social and cultural norms and values. Weber (2010, p. 335) states that in communities where cultural values and worldviews are still part of the daily life these views are the ones who “influence which phenomena and risks they attend”. As a result, their climate change adaptation strategies chosen are focused on providing self-sufficiency in terms of food security, but also in the preservation and survival of values, cultural norms and maintaining their Maya identity (Kuehne, 2014). Compared to Belize their adaptation in terms of timing has also been reactive and responsive, but planned longer-term and strategic in terms of temporal scope (Table 6.7; Smit et al., 2000). This could explain why fewer changes can be observed in *milpas* in Mexico and in adaptation strategies and according to farmers’ narratives they continue to work across time.

Table 7.7. Differences between process and forms of adaptation in Maya Yucatec farming systems in Mexico and Belize (Adapted from Smit et al., 1999).

	Mexico	Belize
Purposefulness	Planned, purposeful and active	Planned, purposeful and active
Timing	Reactive and Responsive	Reactive and Responsive
Spatial Scope	Localized	Widespread
Temporal Scope	Longer-term and strategic	Short-term and tactical
Function/Effects	Protect and restore	Protect and change
Form	Food Security, indigenous knowledge Social and cultural norms and values, cultural identity, financial.	Technological, Institutional Financial/Marketing and Food Security
Performance	Cost-effectiveness, Efficiency.	Cost-effectiveness, Efficiency, Productivity.

The process and forms of adaptation have played a crucial role in the process of knowledge change, but this aspect has been often overlooked in climate science and by external actors working in these communities. The results of this study showed that the knowledge that Maya Yucatec farmers in both countries have been exposed to by external sources, contrary to what is often assumed, are not necessarily helping them to achieve all their priorities and needs, as they are often implemented in a homogenized way and not fully considering local social and cultural elements such as ethnicity or local

worldviews at the community level. Experiential learning in Maya Yucatec communities is then used to survive perceived risks from climate change that threaten their priorities.

The next chapter will discuss how the different levels of adaptation and multiple pathways of resilience (guided by cultural, social and environmental elements) have been developed among Maya Yucatec individuals and communities and the implications of this for their knowledge systems and the *milpa* system. Similarly, based on the findings of this study reviewed within the past three chapters (Chapter 4, 5 and 6) recommendations for future research based will be provided to enhance the understanding of the potential of the Maya *milpa* system in the long-term.

Chapter 7 Discussion

7.1 Introduction

This chapter discusses findings from data collected in six Maya Yucatec communities across Yucatan State, Mexico and Belize using both qualitative and quantitative methods (Chapter 3). The research was mainly focused on documenting farmer's own views, perceptions and experience around the traditional *milpa* system in the face of climate change. Particularly, the research question sustaining this study was: What environmental, cultural and socio-economic aspects do indigenous small-scale farmers prioritize when building resilience to climate change and how do they use and adapt indigenous and other knowledge systems to develop this resilience based on these priorities? By focusing on the same cultural group, the Maya Yucatec people in two different countries (Mexico and Belize), within the same geographical region (Yucatan Peninsula), this study provides four important contributions to the literature on climate change adaptation and resilience among indigenous groups further detailed.

Firstly, the use and adaptation of knowledge in the context of climate change in Maya Yucatec agricultural systems is shaped by three main factors: farmer's priorities, agro-climatic factors and social networks.

Secondly, there are similarities and differences in four main aspects within the Maya Yucatec farmers who practice the *milpa*: 1) in farmers' conception of *milpa*; 2) in farmer's priorities; 3) in farmers' climate change perceptions (See 7.3.1) and 4) in adaptation strategies. Many of the farmers' perceptions and adaptations are socially constructed and interconnected to five aspects: history, power relations, legacy of colonialism, resistance, and self-determination (Ford et al., 2020; Nurse-Bray et al., 2020; Westengen et al., 2019).

Thirdly, holding similar indigenous knowledge does not determine farmers' adaptive capacities and resilience to climate change, but rather their interpersonal relationship with the *milpa* and site-specific factors interlinked with external elements they are exposed to in a daily life (e.g., institutions, socio-economic and political conditions; Dedrick et al., 2023). As a result, different levels of adaptation and multiple pathways of resilience have been developed among Maya Yucatec individuals and communities (Metcalf et al., 2020).

Fourthly, Maya Yucatec people are facing an involuntary cultural adaptation (Reyes-García et al., 2016) because of climate change, including rebuilding and reframing indigenous knowledge (historical and contemporary) into new knowledge approaches (Dedrick et al., 2023; Nguyen, 2019); but also, shifting cultural dimensions of people's lives, social identity adaptation and reorganising social cohesion processes (Adger et al., 2013; Barnett et al., 2021; J. D. Ford et al., 2020).

These contributions highlight how cultural dimensions of climate change are equally important as environmental dimensions as they can also influence resilience and adaptation and the importance of these in the development of climate change strategies. As a result, this chapter also provides recommendations for future research based on these findings and on challenges encountered across the research. Finally, some key points are given from an outsider perspective and as a learner on alternative ways to re-think about how to use, protect and revitalize indigenous knowledge in the context of scientific research.

7.2. The Maya *Milpa* system in Mexico and Belize: What matters now?

7.2.1. Farmer-*Milpa* Relationship and Farmer's Priorities

Results from this research indicate that maize and *milpa* remain active in the livelihoods of modern Maya Yucatec societies (Tuxill et al., 2010). One of *milpa*'s main purpose originally was to preserve native seeds and while this continues to be prioritised for the most part in the studied communities in Mexico, this purpose is changing and has changed in Belize *milpa*. Although there are many factors that have caused changes in the *milpa* system, climate change and the challenges this presents to its management has been one of them, leading to a more frequent use of hybrid seeds. Nonetheless, in most cases, the overall purpose of *milpa* remains the same as in ancient times: to guarantee food security.

Food security continues to be a shared priority among Maya Yucatec farmers in both countries and has guided the continuity of the *milpa* system (particularly of maize cultivation) despite having been modified from its original format (intercropped maize, beans and squash). From the farmers' viewpoint, *milpa* remains present because it is a safety net during challenging times, ensuring that there is always food (Chapter 4, Section 4.2); but has been adapted and shaped to reduce the persistent threat of environmental and socioeconomic changes and the associated risks to livelihoods (Barrera-Bassols &

Toledo, 2005; Faust & Bilsborrow, 2000) aligning with those documented in indigenous food systems in the Peruvian Amazon (Zavaleta et al., 2018).

This system adaptation has led to a re-configuration of the farmer-*milpa* relationship which consequently has also shifted the cultural dimensions embedded as part of it and reframing Maya Yucatec peoples' social identity (Adger et al., 2013; Barnett et al., 2021).

In reconfiguring this relationship, the adaptation process of *milpa* by farmers continues to use multiple-strategies and diversification of resources (Barrera-Bassols & Toledo, 2005), but also multiple knowledge systems which have been adapted and reflect changes in local social-ecological conditions (Ford et al., 2020).

One key aspect that highly differentiated *milpa* systems in Mexico and Belize is that related to farmer's priorities, which vary across countries and have shaped the use and adaptation of knowledge in the context of climate change. The present study found that although contemporary Maya Yucatec farmers' priorities indirectly express the difficult times experienced in the past and from which their contemporary adaptive capacity was built, these priorities are inclined towards different aspects depending on the country and in their "historically specific social situation" Bolland (2003, p. 124). In Belize main priorities are inclined towards market, business and food security, while in Mexico they are inclined towards food security and autonomy, social networks and cultural identity (Chapter 4, Section 4.2.1.1).

Another important aspect found through this research was around the role that history plays in shaping farmers' priorities within indigenous groups, particularly those under the legacy of colonialism and how this has simultaneously shaped their adaptive behaviour and capacity. Dedrick et al. (2023) argue that the historical social challenges faced by Maya people in Yucatan Mexico during the early and late Spanish colonial period forced them to adapt their daily life practices to survive. Cultivation strategies and their social life and networks were two of the main aspects impacted by imposed colonial policies and led to several forms of adaptation that remain embedded in modern Maya Yucatec farmer's priorities and adaptive capacity. Cultivation practices during colonial times were adapted since Maya farmers were often forced to relocate to smaller spaces where they had to learn how to diversify cultivation and shift to quicker food production strategies to guarantee food security, but also to be able to safeguard their food sovereignty from Spanish policies. This led them to continuously assess if local

conditions were ideal to invest in long-term cultivation and to develop a sense of flexibility within their livelihoods (Dedrick et al., 2023), an adaptation strategy widely observed throughout this study.

During colonial times family also played a significant role in their capacity to diversify and improve livelihoods, particularly if extended families were involved. The more extended the family was, the less vulnerable to risk they were, as they tended to cooperate and assist each other. Aside from family, community was also important in colonial times since it was a network of support during periods of famine (Dedrick et al., 2023).

In contrast to this, in Belize, according to Bolland (2003) British colonial settlers' priorities were for the most part inclined towards lucrative trade mostly around timber for the English luxury furniture industry, which took them into the forest inhabited by the Maya people. The native Maya people, forced by colonial landowners and administrators, were forbidden to cut the forest to use it for their shifting agriculture as this could impact the value of the land and the trees. Instead they were persuaded to accept work and wages within their own land and becoming agricultural wage labourers surrounded by many trade and marketing influences which could explain why this priority is deeply embedded in their contemporary livelihoods and they seem to have a less strong relationship with the *monte*. When the mahogany exportation started declining around 1835 the British settlers started looking at other opportunities to continue doing profitable trade. This time however, they looked at the agricultural potential of the Yucatec people who were escaping around that same decade from Yucatan, Mexico into Belize as a result of the Guerra de Castas (Caste War). British settlers started realising the agricultural potential of the Yucatec refugees in Northern Belize as they were cultivating maize, tobacco and even planting and exporting sugar. They started seeing great potential in small-scale farmers systems for agricultural market development giving the lack of certain food commodities in the market from other districts in Belize. British settlers started perceiving Yucatec farmers as agricultural labourers habituated to the climate and familiar with the soil and persuaded them of the profitability of their rice, maize, sugar and even vegetables particularly given that the supply situation was critical due to the Caste War. Guided by the British colonial discourse that subsistence plots were successful and profitable type of agricultural systems that could supply the demands of the market, many Yucatec farmers started replicating this livelihood acquiring ranches (*ranchos*) or renting land to turn them into profitable plantations or ranches. Bolland

(2003) described that despite what was planted both plantations and ranchos were then called *Milpas*; however, although being called the same, the system of production was different on the ranchos and guided more like the traditional Maya *Milpa* shifting cultivation management, animal power and simple processing equipment. In contrast, plantations were managed following a short-term fallow system and more sophisticated equipment and technology. Small *milpas* (ranchos) were mostly for subsistence and only a reduce spaced was cultivated for cash crops, while big *milpas* (plantations) were managed mostly for sugar cultivation. When the demand for sugar started increasing, plantations started dominating the northern agricultural landscape thus modifying the “cultural ecology and social structure” and neglecting many of the traditional Maya culture Bolland (2003, p. 116). This became more common in the 1860’s when agricultural estates were consolidated, and the agricultural market started being dominated by big-landowners and colonial administrators, displacing small-scale farmers and instead becoming agricultural labourers subject to discriminatory and racial restrictions under a colonial framework. Under this framework Maya Yucatec in Belize were scattered to village-homes with their families, “dispossessed and denied the right to own land forcing them into a capitalist-colonialist society” Bolland (2003, p. 125).

The legacy of colonialism appears to be deeply embedded in the agricultural life of Maya Yucatec people and could explain why contemporary *milpa* in Belize is perceived, managed and cultivated towards crop diversity for profitability. The conception of *milpa* remains the same as in colonial times where any cultivation plot can be called *milpa*, despite having only a small amount of maize, but the management can change based on farmers’ embedded priorities. This legacy could also explain why *milpas* in Belize continue to have a “replica” approach guided by social networks (e.g. neighbours or other landowners). Mostly it could explain why indigenous knowledge is less present and less used in Maya Yucatec people in Belize.

Despite the different ways and situations that led *milpa* to be shaped to their current status, social networks (social capital) continue to be part of farmer’s priorities in Mexico and Belize and are an important factor that has helped them to build resilience (Carmen et al., 2022) but also have played a key role on how their adaptive capacity and their use of knowledge is being shaped.

7.2.2. Adaptive Capacity in Modern Maya Yucatec Societies.

Results from this research indicate that Maya Yucatec farmer's adaptive capacity has been a form of survival and resistance to fully dominance of external governance, this however hasn't prevented them from experimenting with modern sources of knowledge and technology for crop diversification, as was done during colonial times to overcome challenges. Relationships with nature, social networks, agro-climatic conditions and land have been at the top of Maya Yucatec priorities in Mexico since colonial times and adaptation strategies based on autonomy and resilience continue to be the axis of decision making in modern *milpa* (Dedrick et al., 2023).

This study found that contemporary strategies adopted by farmers in Mexico continue to prioritise land management and agricultural input practices and are driven by farmer's own knowledge (Chapter 6, Section 6.6.2) like that reported by (Granderson, 2017) in Melanesian communities in Vanuatu. These strategies not only allow them to protect their land and local resources from climate change which are necessary for securing their livelihood (*milpa*), but also allow them to protect their autonomy as a cultural group including their cultural values, worldviews and knowledge. Adaptation is not only built from an environmental and socioeconomic perspective, but also a form of cultural adaptive capacity (Reyes-García et al., 2016).

In Belize, adaptive capacities are also rooted in historical and colonial practices from British settlers, but the drivers are different from those in Mexico. As mentioned in Section 7.2.1 early colonialism in Belize forced Maya people to adopt an economic development and business approach when practicing agriculture as a response to economic and societal needs in the country (Bolland, 2003). As a result, the Maya Yucatec farmers in Belize shifted their approach to producing food not only for survival, but for engaging in economic strategies that could help them to get higher economic benefits in return of their investment to land management. This approach has continued to be replicated in the country by local institutions; thus, indirectly shaping farmers priorities and informing farmers decision-making and adaptation strategies.

This influence is reflected in their contemporary adaptation strategies which although diverse and reflecting the diversity of the modern agricultural systems in the country, are all inclined to marketing and economic development (Metcalf et al., 2020). The aim of these strategies has been towards producing higher value crops guided by market trends

and towards improving their agricultural systems to achieve such goals. This economic agricultural approach reflects Belize's historical dependency on regional and international trade networks since most of its local and foreign exchange come from tourism and agriculture of crops that can be traded with neighbouring regions (Requena et al., 2019). As with ancient Maya civilizations, for Maya Yucatec farmers in Belize, trade continues to play an important role in their livelihoods and hence their need to prioritize this aspect when building resilience (Turner & Sabloff, 2012).

An important aspect that was found in this research has to do with the barriers that are limiting farmer's adaptive capacity. One of those barriers has to do with the adaptation strategies promoted and implemented by local institutions, which from the farmer's point of view continue to be disconnected from local environmental and cultural contexts (Chapter 6). In analysing this perception, it appears that many of the adaptation strategies promoted are based on a similar adaptive space without careful consideration of relevant aspects such as micro environmental conditions, the diversity of management practices implemented by small-holder farmers or the social identity of farmers. There is also a remarkable lack of attention towards indigenous knowledge systems, reflected in the farmers' shared perception of disregard of their traditional governance and knowledge systems when working with government authorities; which consequently has prevented farmers to fully implement such adaptation strategies.

As a result of these barriers, Maya Yucatec farmers in Belize have had to reshape their own knowledge and cultural values into new knowledge approaches and although different from farmers in Mexico, Maya Yucatec farmers in both countries have developed a cultural adaptive capacity (Chapter 4 and 6) that has enabled them to protect what is left of their culture, their knowledge and their governance systems (Lyons et al., 2020). As discussed in their work within the Arabana Indigenous communities in south Australia by Nursey-Bray et al. (2020, p. 19), this cultural adaptive capacity is aimed to "assert their own sovereignty by building their own responses and find ways to integrate their activities with pre-existing, and largely, Western dominated models" given the limitations faced.

7.3 The effects of climate change on the Maya *Milpa*: Insights from Yucatec communities in Mexico and Belize

According to (Turner & Sabloff, 2012, p. 13912) throughout history (e.g. Late Classic period ca. 900 CE) climate variability and particularly drought have been “an important exogenous forcing on human–environment conditions” in the Yucatan Peninsula Region; but there have also been other internal factors that have historically increased the impacts of climate change.

According to this study climate change remains the biggest environmental and social challenge for contemporary Maya Yucatec agricultural systems in the studied communities in Mexico and Belize, with farmers facing both physical and non-physical impacts (Chapter 6, Section 6.6; Thomas et al., 2019). Simultaneously climate change is perceived as one of the main drivers of change in the traditional *milpa* system, but not the only one.

Changes in *milpa* have been the result of farmers adapting to variable agro-climatic conditions and the most evident change has occurred within farmer’s agricultural calendar (Chapter 6, Section 6.6.2) aligning with findings from farmers in northern India (Paul et al., 2023), in small island communities in Southeast Asia (Hiwasaki et al., 2015), the Maya Ch’ol farmers and Zoque people in Chiapas, Mexico (Briones, 2018; Sánchez-Cortés and Chavero, 2018) and in communities in southern Uganda (Orlove et al., 2010).

Although each stage of the *milpa* depends on agro-climatic conditions, *milpa* is managed under a biocultural approach and different cultural dimensions are embedded within the system which can influence individual farmer’s social identity and their relationship with the system (Chapter 4). Research has found that climate change adaptation can be influenced by people’s social identity (Barnett et al., 2021) and their perception of threat related not only to a physical aspect of the system, but to their own social identity. As a result, a farmer’s adaptation process is built not only at the environmental, but also at the social and cultural level (Adger et al., 2013). Therefore, in order to understand the adaptation process, it is important to first understand the perception of the threat from a farmer’s view.

7.3.1 Farmers' perception of climate change: Interlinking indigenous and scientific assessment to understand changes in local microenvironments.

Overall, farmers in both countries believe that climate change is occurring and is caused by anthropogenic activities, mostly by deforestation and by their own farming activities. Farmers' beliefs around climate change appear to be shaped by the direct impacts faced in their own farms as a result of the continued climate variability in the region, but also by the influence of local social networks (both from the community and institutional, Chapter 6, Section 6.5.1).

In relation to the main changes in agro-climatic conditions, according to this study the most observed and perceived changes by farmers in Mexico and Belize have been rainfall variability and higher temperatures (Chapter 6, Section 6.5.2). These results are like those reported in farming systems in indigenous groups in Asia and Africa (Kangalawe et al., 2017; Serdeczny et al., 2017). However, when analysed at the community level, climate change perceptions are not necessarily homogenous and differ in terms of occurrence and severity (Chapter 6, Section 6.5.2.1 and 6.5.2.2), aligning with findings from Van Gevelt et al. (2019) in Malaysian Borneo. Heterogeneity in community perceptions is indirect evidence of the regional heterogeneity, particularly in relation to rainfall variability across the Yucatan Peninsula and which has been previously described by De La Barreda et al. (2020).

Most of the local perceptions documented in the present research were consistent with meteorological records (climate anomalies; Chapter 6; Section 6.3.4 and 6.4.1); however, some inconsistencies were also reported (Metcalf et al., 2020; Van Gevelt et al., 2019). These inconsistencies could be the result of farmers' uncertainty in trying to define or distinguish between specific weather conditions and its severity and should be considered in future studies. But they are also indirect evidence that farmers' access to climate information continues to be limited despite their different relationships with local stakeholder and despite their access to government support aiming at mitigating the impacts of climate change.

These results highlighted the need for local governments to a) provide farmers with better and continued access to climate and weather pattern information using both scientific and IK-based approaches and b) build joint climate-based assessments to ensure farmers can easily recognise, name and assess changes in local weather conditions. In doing this it is

important to provide guidance on the relationship of climate variability with other elements from the agricultural landscape such as soil, while also assessing and jointly recording how changes on such local environmental conditions are potentially impacting other aspects of farmer's life such as socioeconomic and cultural aspects (Abid et al., 2019; Hughes et al., 2022).

One key aspect to consider when providing information about microenvironments and that was considered for this research, is around soil. *Milpa* productivity in the Yucatan has been historically associated with the heterogeneity of soils present in the region and different soil characterizations have been done Bautista et al. (2003) and Estrada-Medina et al. (2013) several of them interlinking indigenous knowledge. Despite this and the extensive soil knowledge that farmers possess innately as documented in this research (Chapter 5, Section 5.3.1.1), soil health is one of the elements that continues to receive less attention by local stakeholders.

While building an on-site characterization of soils guided by farmers' own knowledge, this research provided evidence that farmers can easily assess changes in soil diversity and that farmers' own characterization of soils can be crucial not only to fill gaps when interlinked with scientific descriptions, but also in some cases could be the only resource available to enhance descriptions that have not been updated like those in Belize (Chapter 5, Section 5.3.1) since the country lacks of capacity to assess local soil conditions.

Results from the joint soil assessment conducted through this research provided evidence that *milpa* as an agro system has also been a model of resilience in terms of soil management, as the dynamic changes of *milpa* since colonial times have been focused on assessing local soil and weather conditions to make decisions (Dedrick et al., 2023) and continues to be replicated by farmers. Soil management within the *milpa* has also evolved and been adapted and although farmers are not familiar with modern descriptive concepts of soil properties (e.g. organic matter, texture), they do recognise these elements in practice and have adapted their farms based on their own notions of soil quality.

Farmer-based perceptions of microenvironments and their assessment could be beneficial and practical when trying to design and implement local strategies, and is important because past research has shown that perceptions and expectations around local conditions can change across time and thus shift adaptation strategies (Hughes et al., 2022; Niles & Mueller, 2016). In countries like Belize where farmer's priorities are

inclined towards market and business, following this approach could help to better understand farmers priorities and impacts when dealing with climate change and consequently help to improve the way of providing financial aid based on such assessments.

Similarly, the use of local traditional monitoring assessment of environmental conditions, such as indigenous soil classification and local weather forecasting methods, like bioindicators, should be incorporated into research paradigms to assist with the development of IK-based local warning systems (Jiri et al., 2016) as this could also help to improve the local strategies to mitigate climate change impacts on different levels.

According to this research the impacts of climate change have been felt by Maya Yucatec farmers at an environmental, social, economic and cultural level. Impacts have indirectly affected key elements of Maya Yucatec peoples' lives such as food security, culture, social identity and knowledge systems (Chapter 4; Chapter 6) and, although not investigated in this research could also be impacting health (Haines et al., 2006) and family economy and income (Di Falco et al., 2012; Senapati, 2020). Similar findings have been reported in traditional agricultural regions in Sub-Saharan Africa (Serdeczny et al., 2017).

These impacts have translated into 1) changes in the local conditions including the weather and the soil, but also in an increase of pests (Malhi et al., 2021; Serdeczny et al., 2017) and 2) transformation and/or erosion of indigenous knowledge. Other changes such as reduction in the annual yield as a result of crop loss impacting farmer's annual income (Prokopy et al., 2015; Serdeczny et al., 2017) might be also occurring and should be considered in future research.

These impacts are indirectly interrelated and provided evidence of why interlinking knowledges is useful when understanding how resilience is built by farmers and why different perspectives should be considered. The above could be exemplified when explaining soil management and *milpa* resiliency. Farmers in this research considered that the incorporation of technical agricultural inputs such as agro chemicals, the use of hybrid seeds and the homogenization of modern agricultural systems are actions that are impacting land diversity. As a result, the knowledge that farmers have built across time in relation to soil is also being affected and challenging the resilience process they have built around this element. This, however, hasn't limited their capacity to continue to

respond actively to changes since in some cases they have continued to enhance the agrobiodiversity present in *milpa* as a mechanism to also reduce their vulnerability. In doing this they have used different knowledge systems, however limited access to crucial modern knowledge (as with microclimates), is posing a challenge to their resilience particularly in a region where interlinked dimensions and factors can increase vulnerability.

Because impacts are interconnected, joint assessments that integrate multiple dimensions of climate change and different knowledges should be highly prioritised in countries like Mexico and Belize which could consequently also simplify the way farmers adapt and could break the invisible barriers they continue to face when trying to implement adaptation strategies.

7.3.2 Climate change adaptation strategies in the Maya *Milpa*

Results of this research showed that climate change adaptation in Maya Yucatec communities is heterogenous and interlinked to multiple climatic and non-climatic stressors. In terms of adaptation strategies, these varied between countries (Chapter 6, Section 6.6.2) and are being implemented and driven by different reasons. This research found that adaptation is influenced by mainly three main factors: a) beliefs and experiences around climate change, b) individual priorities and c) social networks.

Changing and adjusting planting times continues to be the most reliable strategy, as has been reported in other studies in the area (Harvey et al., 2018; Mardero et al., 2015; Metcalfe et al., 2020). This strategy exemplifies the multidimensions looked at by Maya Yucatec farmers when building resilience, but something that is often dismissed by the adaptation strategies implemented by external agencies.

Changing and adjusting planting times is mostly used as a result of their experiential learning and considering its cost-effectiveness (Masud et al., 2017) but also, because it has allowed them to continue being productive even during challenging times, meeting their subsistence needs (food security) and without depending fully on modern technologies (which can be expensive and uncertain in terms of effectiveness). For some farmers, this strategy has also helped them indirectly to keep themselves attached to key indigenous knowledge on which their social identity and culture depends. Although diversifying their planting times could appear to be risky in a region with marked weather variability, this strategy has historically proven to help them recovered from extreme

events and to conserve crucial farming resources (e.g. native seeds; (Altieri et al., 2015). The success of this strategy perhaps lies in the fact that it considers the multiple dimensions that farmers ponder as relevant and because their main priorities remain secured.

The adaptation processes developed by Maya Yucatec people are multidimensional (Adger et al., 2013) and could explain why in a similar ethnic group facing a similar challenge (climate change), individuals from the same community could display very different adaptive capacities; as a result changes implemented occur not only in the *milpa* but also in their own identity and behaviour (Jaspal et al., 2014) depending on which environmental or cultural dimensions of climate change they are experiencing.

Therefore, working with indigenous communities, assessment and integration of multiple dimensions of climate change is important as it could help to identify other benefits and areas of opportunity for farmers in relation to climate variability. For example, results from this study showed that although farmers have been impacted by climate variability, it has also brought some benefits and has opened the door to new farming opportunities. Specifically, among farmers in Belize, climate variability has allowed them to diversify their planting calendar and take advantages of delayed and increased rainfall during the winter months (Chapter 6; Section 6.7.2; Prokopy et al., 2015) which is also another type of adaptive capacity that has been developed.

The majority of farmer's adaptation processes have also included a unique (always overlooked) strategy to enhance the resiliency of *milpa* through improving soil ecology by taking advantage of micro-climate variability and developing trial-error strategies on-site that can allow them to respond to soil changes or other impacts such as reduction or fluctuations on soil moisture as a result of changes in temperature (Altieri et al., 2015). As mentioned in Section 7.3.2, modernization of agriculture has also led them to adopt other adaptation strategies that could not necessarily be helping them to mitigate the impacts of climate change (Abid et al., 2019; P. Smith and Olesen, 2010). For example, following a replica approach despite their vast experiential knowledge of soils due to temporary results achieved when using synthetic agricultural inputs rather than the organic approaches that have developed across time could not necessarily be the most suitable for their plots. Many farmers, especially those with larger extensions of land are prioritising this type of management strategy, that is less time consuming, to achieve

more productivity for increasing their market outputs. In doing this however the resilience of the whole *milpa* system might also be compromised and could increase their risk and vulnerability in the long term, especially as mentioned before if access to crucial information about microenvironments is limited or overlooked.

Documentation of these practices, as stated by Abid et al. (2019, p. 122) portrays important constraints that farmers face when adapting their farming systems “such as limited access to resources, information, and institutional services” which can have important implications for elements that have been historically relevant like food security.

Despite this potential risk, this could also be the answer to why they are willing to experiment with different types of knowledge. Diversification of knowledges is potentially helping them to test out which adaptation strategies can improve (or not) the resilience of their agroecological systems (Altieri and Toledo, 2011) and in doing so they are willing to temporarily experiment in order to achieve that goal.

7.4 The use of indigenous and other knowledge systems by Maya Yucatec societies: A review.

The present study documented different forms in which indigenous knowledge is used in contemporary Maya Yucatec communities in Mexico and Belize which appear to be rooted in historical colonial knowledge. This knowledge is used in varied ways and levels across different aspects of their daily lives including farming, cooking, health and weather forecasting.

When comparing how Maya Yucatec knowledge is used in the studied communities, similar concepts associated to the *milpa* were recorded (e.g. planting strategy, annual weather forecasting/*Xo'okin* or cabañuelas, moon phases, *Cha cha'ak* rituals, thanksgiving offers/*primicias* bioindicators; See Table 5, Chapter 4, Section 4.1). Within these type of indigenous knowledge, the use of the moon phases across is prioritised across different stages of making *milpa* (e.g. planting and harvesting) and often the most reliable source of indigenous knowledge for crop productivity in both countries given that compared to other rituals and traditions this hasn't really been impacted by climate change.

Remarkable differences were found across countries in how indigenous knowledge is used based on farmer's individual priorities. In Belize, indigenous knowledge is used in

specific aspects of farming, mostly related to increasing crop productivity which aligns with their market and business priorities. When building resilience to challenges this knowledge is used mostly as a back-up resource for example during Covid-19 when due to high prices of fertilizers and agricultural input forced them to rely on the use of their indigenous knowledge to continue farming (See chapter 5;section 5.2) but also to protect themselves from the illness (See Chapter 6; section 6.7.4).

Indigenous knowledge related to agriculture in Belize has suffered a more evident process of transformation and reconstruction (mostly due to the modification of cultural contexts and relationships of Maya Yucatec with nature) compared to Mexico and only indigenous knowledge that has proved to work for farmers in Belize remains active. Just as in colonial times Maya Yucatec farmers in Belize have continued to develop their livelihoods and modern social and cultural networks around the concept of economic development.

In the case of the Maya Yucatec communities in Mexico, indigenous knowledge is still widely used in daily life and particularly in agriculture. However, narratives and discourses around progress and success, influenced by those who have migrated outside the community to popular tourism destinations, pose a challenge to the transmission frameworks.

Use of indigenous knowledge is not homogenous and varies notably within communities across both countries depending on their individual connection (social identity) towards nature and cultural elements, but also to their exposure to external elements. For example, a farmer in Western Belize from one community (San Jose Succotz) who had diversified his agricultural system and has had access or exposure to other sources of knowledge, still uses the moon phases as it is part of family tradition (See Chapter 4;Section 4.2.1.1). Other traditional elements such as the use of native seeds are, however, no longer a priority for the family as they don't provide economic benefits and involve a lot of time and effort (Farm 7-HY). On the other side, a farmer in the same area but from a different community (San Antonio), who changed his perception of productivity at an earlier age and has been exposed to other techniques such as those used by Mennonites (Chapter 4, Section 4.2.2), doesn't use the moon phases anymore, but has transmitted the knowledge to other members of the family who can decide whether to use them or not since it's part of the Maya Yucatec tradition of knowledge transmission. Despite exposure to other

techniques and having also diversified his agricultural system he continues protecting his native seeds as it is a tradition and a priority of Maya Yucatec culture (Farm 6-L Y). These results showed that Maya Yucatec knowledge is also directly related to aspects of identity as found with the Lahu people in Thailand (Nguyen, 2019) and that have led to new local environmental and social narratives.

Despite the differences in the way Maya Yucatec communities prioritise and use indigenous knowledge, Maya Yucatec language is still used when it comes to naming environmental elements such as soil, maize varieties, climatic elements (rain, wind). However, observations from this research showed important variations to linguistic conceptualizations associated to relevant elements of *milpa* (e.g. soil classifications; Chapter 5, section 5.3.1.1) which could be also a type of cultural adaptation resulting from the impact of climate change and which should be further studied.

In addition to this, more research on what exactly is happening with intergenerational transmission and convergent and divergent transmission and knowledge acquisition frameworks is needed to better understand the level of impact of climate change on cultural adaptation across different generations of Maya Yucatec people.

7.4.1. Types of knowledge used by Yucatec Maya farmers in Mexico and Belize in traditional agriculture in the context of climate change.

Modern Yucatec societies in Mexico and Belize, where this research took place, provided evidence that indigenous knowledge (IK) is used along with modern science and technology developments to build resilience to climate change. Despite a close relationship with external agents and development programmes, IK in relation to astrological cycles for agriculture continues to be prioritised among Maya Yucatec farmers within the study areas over modern science.

Aside from IK, other forms of knowledge and the similarities and differences of how they are used across *milpa* was documented and provided further understanding of how knowledge adaptation occurs at the community level. In the studied Maya Yucatec communities, the use of specific types of knowledge in agriculture is linked to the kind of narrative and discourses that community members are exposed to either from government or private or public research institutes.

Knowledge adaptation is socially constructed as it is influenced by narratives of their social networks and working approaches around economic development in their communities in the case of Belize and about progress and innovation in the case of Mexico.

In both countries, these narratives have made farmers believe that in order to progress, certain knowledge and techniques need to be followed, but often these approaches lack of local context results in farmers finding them less relevant to their community practices. As a result, according to Cajete (2020, p. 11) “indigenous communities may apply conventional models of Western economic development out of sheer necessity to serve pressing needs...but often face challenges which prevent them from utilizing these models to their full potential”.

A shared perception by farmers within the study areas in relation to the use of modern science and technology is that it continues to replicate structures of injustice, since putting into practice much of the knowledge from external agents requires financial efforts disproportionate to the economic context and capacity of small-scale Maya Yucatec farmers. In addition to this, some Maya Yucatec farmers also shared the belief that external agents’ programmes are “a way of subduing local agriculture and farmers” because they control and take advantage of financial needs for their own benefits (Farm 3-LNXY; Farm 7-HY, personal communication). Thus, agriculture continues to have little significant economic progress and benefits and access to modern knowledge continues limited to certain farmers (Farm 1-HST and Farm 6-LY). This perception has been explained by Cajete (2020, p. 11) as a legacy of colonization and explains that it is given that “indigenous communities and their economic development efforts are viewed by governmental or private funding agencies, as poor or marginal risks at best and always in need of external co-signers or capital”.

In Belize, this was observed since farmers can access subsidies or loans for acquiring agricultural inputs, but because these businesses are limited in the country and are dependent on imports from other countries, prices are disproportionately high relative to the farmers income. In addition to this many of the farmers surveyed expressed that the government has a “privileged list of farmers” that leaves out many farmers who really depend on agriculture and preference is given to “temporary farmers” or those with strong connections with the government. A similar perception was documented in

Mexico in terms of privilege of access to government programme support which hinders opportunities to those truly in need given the many bureaucratic processes involved. Prices are more regulated in Mexico but still farmers struggle a lot since the prices are very volatile. In both countries, farmers surveyed and interviewed expressed that corruption plays a great role in accessing and receiving support for small-scale agriculture and that is one of the causes why smallholder farmers continue to be in poverty (Farm 4-LGR, Farm 2-LM).

Despite this perception, the present study found that farmers in the study areas do not neglect collaboration with external agents and do recognise that these collaborations are essential given the current challenges being faced; however there is a shared perception that collaborations should be thought through the perspective, needs, values and priorities of the farmer and their local settings, rather than from external contexts, as this poses additional challenges to adaptation (Hill et al., 2020) and that indigenous knowledge should be also used to inform climate change policies (Lyons et al., 2020).

The perceptions documented in this study, although showing a current use of indigenous and modern knowledge in traditional agriculture, also provided evidence that there are alternative types of knowledge that Maya Yucatec farmers associate with *milpa* resulting from their capacity to combine and create new knowledge to cope with contemporary challenges such as climate change.

7.4.3. Use and adaption of knowledge systems as a mechanism to build multiple pathways to resilience.

Social, cultural and environmental settings have changed in both countries which have directly impacted farming priorities and have led to a new emerging knowledge that rather than being transmitted across generations (Berkes, 1999) is the result of information gained convergently through individual experience and transmitted divergently (Nguyen, 2019). This knowledge has also emerged as the result of “practices that have fallen out of favour in government resource management, presumably because of production inefficiency but that are being rediscovered” according to Berkes et al. (2000, p. 1254). Similarly, this knowledge rather than focusing on standard approaches to ecosystem management (Berkes et al., 2000), has been reshaped to focus on a management that consider multiple dimensions embedded in complex social-ecological systems (Preiser et al., 2018).

Therefore, based on the results of this study, and adapting a similar approach used by Nguyen (2019) within the Lahu people in northern Thailand and building on findings from Nursey-Bray et al.'s (2020) work with the Araba Indigenous people in southern Australia, the research identified that there is also a third unrecognised and overlooked knowledge used within the Maya Yucatec people that for the purpose of this study will be called *adaptive indigenous knowledge (AIK)*.

This knowledge has emerged and has been built as a strategic response in the absence of a capacity to fully use and apply their indigenous knowledge to current challenges, but also due to a lack of capacity to fully adopt modern science given the multiple local barriers faced. This knowledge is rooted in their contemporary ways of viewing tradition, is representative of their own priorities and is the result of their historical knowledge (ancestral and colonial), their adaptive capacity and their contemporary experience. In climate change adaptation discourses, indigenous knowledge is often seen as a resource that can complement areas where modern science is limited, but AIK breaks with that misconception by intersecting bodies of knowledge and discourses to evolve into a full knowledge approach (Nguyen, 2019).

AIK has been built following acquisition and transmission frameworks different from their own indigenous knowledge. AIK is an intersect body of knowledges acquired from different sources (convergent) within members of a same cultural group and transmitted through different channels (divergent) between other members from the same cultural group, but not necessarily from the same family. Contrary to IK, which is often considered as context-specific (Lutomia & Bello-Bravo, 2017), AIK considers hybrid-contexts and is built around different discourses (Nguyen, 2019; Nursey-Bray et al., 2020). Epistemologically speaking it still follows a specific ethos and relationality, but rather than focusing on an ethos of care and a human-nature relationship, given a quick transformation of their surroundings, it is being shaped around an ethos of survival and resistance and a relation to human-resource-challenge (Table 7.1).

Table 8.1. Characteristics of Indigenous knowledge vs Adaptive Indigenous Knowledge proposed for this study.

	Indigenous knowledge	Adaptive Indigenous Knowledge (adapted from Nguyen, 2019)
Definition	Body of traditional environment and cultural knowledge unique to a group of people which has served to sustain that people through generations of living within a distinct bioregion (Dedrick et al., 2023).	Intersect body of knowledges acquired from different sources within members of a same cultural group
Context	Context-specific (Lutomia and Bello-Bravo, 2017).	Hybrid-context
Development	Generational across time built on own observations.	Built around all discourses useful to their priorities and creatively adapted (Nguyen, 2019).
Acquisition	Linear	Convergent
Transmission	Linear	Divergent
Worldviews and Values	Tradition, Spirituality, Respect, Reciprocity.	Identity, Community, justice, resistance and survival.
Ethos and relationality	Relationship nature-human and ethos of care.	Relationship human-resource-challenge and ethos of survival and resistance.
Social mechanisms	Collective action.	Individual action through integrated views.

Considering the above, it can be assumed that IK is present in all the studied Maya Yucatec communities in Mexico and Belize. However, farmers in Belize have transitioned from the use of IK alone, to the development and use of an AIK to build resilience to climate change compared to farmers in Mexico who still rely heavily on indigenous knowledge but are slowly transitioning into that approach.

Both IK and AIK belong to and are held by the Maya Yucatec people, but the indigenous knowledge historically shared has been re-examined and reconstructed into an Adaptive

Indigenous Knowledge as a socially enforced mechanism of survival, resistance and for resilient resource management. This strategy has been documented in different indigenous groups across the globe in the Arctic, the Pacific Islands, the sub-Saharan Africa and those inhabiting tropical forests and was highlighted in the work of Ford et al. (2020, p. 538) who argued that indigenous people are “continuously reclaiming, re-energizing and rebuilding their knowledge systems in light of environmental change and other outside pressures that can support rapid adaptation during times of change”.

The authors also state how this knowledge adaptation can be developed into “new knowledge heuristics (e.g. new seasonal calendars), new livelihood strategies (e.g. altered cropping practices) and evolution of protocols of knowledge transmission” (Ford et al., 2020) hence the importance of documenting this within climate change studies. This is what appears to be happening in Belize and to some extent in Mexico, leading to the regeneration and creation of new knowledge approaches, and where some non-relevant past agricultural knowledge is being dropped.

Recognition of alternative knowledges is relevant given that in climate change adaptation discourses, literature often only recognises two ways of knowing, or categories of knowledge (indigenous/traditional or modern knowledge), to be the ones potentially used by local societies when building resilience and adapting to climate change. Amongst these two knowledge categories there is often a common perception within the literature that adaptation of local or indigenous knowledge is almost the only way for indigenous people to build resilience in the face of challenge. Although adaptation of indigenous knowledge as a climate change coping mechanism is happening and has been documented in the literature (Antwi-Agyei and Nyantakyi-Frimpong, 2021), by doing this, indigenous people and their knowledge systems have been indirectly pigeonholed into solely a capacity of adapting rather than highlighting their capacity for reconstructing different types of knowledge, including their own indigenous knowledge and potential for creating and validating new knowledge approaches, which is the basis of indigenous epistemology (Gegeo and Watson-Gegeo, 2001).

Evidence from this study in Mexico and Belize has revealed how indigenous epistemology is developed and applied in the face of challenges and in doing that how modern indigenous societies are reconstructing knowledge and validating experiences that allows people to survive. It can be assumed then, that IK continues to be used by

some farmers as the main tool for climate change adaptation, but AIK is the one being retained and more often prioritised by Maya Yucatec people from the studied communities. This doesn't mean that modern science is not used, but it plays a specific role in Maya Yucatec farmers in Mexico and Belize as it has provided farmers with access to some information about climate change for decision-making (See Chapter 6; section 6.5.1), however given that accessibility isn't granted on a formal and regular basis, AIK has more often become the way to face challenging times.

7.4.4 Climate change adaptation strategies and use of knowledge systems

Evidence in this research showed that there are differences in the adaptation strategies implemented by Maya Yucatec communities in Mexico from those in Belize in terms of management (See Section 7.1), but also in terms of use of knowledge in the face of climate change.

Changes in the planting calendar as an adaptation strategy (See chapter 7; Section 7.3.2) have brought significant impacts to cultural elements that are part of Maya Yucatec traditions (pre- and post-colonial traditions). For example, in the traditional Maya agricultural calendar, native/creole maize should be planted in May since it is when Saint Isidore the Labourer (patron of farmers) is honoured and always before the *Cha chaak* ceremony. However, the *Cha chaak* is another example of cultural disruption caused by climate change, since this ceremony is supposed to be performed right before the *canicula*/hot summer sun (15 July-15 August) but this may no longer occur at that time as dictated by the Maya tradition, because planting often hasn't occurred yet. Similar changes in indigenous farming calendars have also been reported in Northeastern India (Paul et al., 2023), in Central America (Harvey et al., 2018) and in Africa (Antwi-Agyei & Nyantakyi-Frimpong, 2021).

Climate change has also posed an additional challenge to traditional ways of knowing such as weather forecasting, making it less reliable and altering traditions that are the basis and foundation of Maya Yucatec culture. This has indirectly also affected elements that are characteristic of the cultural group, such as the use of native seeds and the indigenous knowledge around them, which has brought additional challenges to farmers in the studied communities as some of them (e.g. Farm 1-HST and Farm 6-LY) have chosen to switch to hybrid seeds instead since they are less time consuming and yields are obtained quicker. As a result, their conventional resource management, from where

Maya Yucatec ethos, values and relationality originate has been eroded and thus not transmitted to younger generations.

Adaptation of cultural values and ceremonies is occurring as a result of changes to their farming calendar so that this can be aligned with agro-climatic conditions. This is evidence that climate change is not only impacting environmental elements but is also threatening cultural and societal elements which consequently can shape farmer's priorities indirectly causing a form of cultural exclusion in their own territories and disrupting cultural identity.

Even though there is an extensive local knowledge about soil properties based on farmers' observations and which aligns with descriptions available in the literature (Bautista et al., 2003; Estrada-Medina et al., 2013b), this knowledge is not prioritised by external agents in terms of health (soil health), but instead just in functionality and productivity which is reflected in the knowledge transmitted to farmers (pest control and use of fertiliser).

As a result, farmers despite having a vast innate knowledge of soils, do not see soil quality as a management priority compared to other management activities such as irrigation, despite the relevance for their future livelihood security which highlights a maladaptation trajectory that can potentially increase their vulnerability to food insecurity in the medium term. Soil is a climatic and non-climatic driver for food security vulnerability, and evidence of this has been reported within the Peruvian Shawi indigenous people (Zavaleta et al., 2018). Therefore, soil health and interlinked management should be a priority by both farmers and external agents in Mexico and Belize.

Climate change adaptation in the research areas continues to be assessed in terms of environmental impact; however, intersectionality with socio-economic aspects and cultural drivers are mostly not considered and that is reflected in how farmers perceive the approaches of external agents to be decontextualized.

Despite Maya Yucatec people being present in both Mexico and Belize, currently there are no formal mechanisms in place in either country to assess the use of knowledge systems at the community/local level in terms of climate change adaptation within the studied communities. Similarly, there are no mechanisms in place to assess the role of traditional institutions and conventional institutions (government and development programmes, research collaborations) in such adaptation.

The integration of mechanisms that can assess community and individual priorities, values, traditional sources and traditional institutions into the current agricultural assessment is needed in multicultural countries such as Mexico and Belize. However, the main challenge in doing this is that there is a tremendous separation between local and traditional institutions and conventional local institutions (e.g. Institute for Social and Cultural Research, MoA, and Caribbean community Climate Change Centre-CCCCC in Belize).

Findings of this research are relevant in the context of in-country collaborations and contribute to the arguments for the importance of understanding local knowledge systems as essential for climate change adaptation. This aligns with findings from Nursey-Bray et al.'s (2020) work with the Arabana People in Southern Australia who argue that when documenting perceptions in indigenous territories “how knowledge, is understood, mobilised, and disseminated is a fundamental dynamic when seeking to understand perceptions and responses about climate change” (Nursey-Bray et al., 2020, p. 147).

7.5 The importance of integrated approaches in researching social-ecological systems: The case of the Maya *Milpa* in Mexico and Belize

7.5.1. Benefits and Challenges of Transdisciplinary and Transnational Research

In using transdisciplinary and transnational research there were important contributions made to empirical research that align with the results of a two-decade systematic review around climate change adaptation amongst indigenous groups conducted by Taylor et al. (2023). Their research highlighted four points discussed by the authors which are often left out:

“1) the need to conduct additional studies in the Pacific Islands and Central and South America, where increased vulnerability emphasizes the importance of adaptation; 2) the need for researchers to expand sectors included in studies, such as health and cultural adaptation; 3) researchers and practitioners to employ participatory methods; and 4) researchers and practitioners to situate adaptation in the context of colonization.” (Taylor et al., 2023, p. 20).

Findings from the studied Maya Yucatec communities addressed all the points above and provided relevant information for Mexico where, although climate change research has been widely done, the present study contributes to filling important gaps at a cultural level. As for Belize, where literature is scarce, as is the case for many countries in Central

America, results contribute to a better understanding of climate change adaptation and resilience both from an environmental and cultural perspective. Focusing the research on the role of knowledge systems within the same cultural group provided important insights into cultural adaptation in the face of climate change rather than focusing exclusively on environmental and social adaptation.

Although the methods used within the research followed quantitative and qualitative approaches (mixed methods), the research used some participatory approaches as part of the collaboration with Maya Yucatec farmers and was useful to gather insights about the relevance of transdisciplinary research and the need for conducting more research of this kind.

One of these approaches was the development of an agricultural calendar which combined both indigenous concepts from Maya Yucatec farmers in Belize and Mexico and scientific knowledge in terms of weather forecasting. Consultation, verification and design of the calendar was done by both farmers and the researcher to integrate not only indigenous or scientific knowledges, but other alternative knowledges (e.g. adaptive indigenous knowledge) into one tool useful for farmers in both countries. Illustrations for each month were provided by farmers and their families using their own photographs that reflect the way they view important elements and dates/stages of the *milpa*. Once prepared and reviewed by both farmers and researcher the calendar was printed and disseminated for 3 consecutive years in the studied communities through the duration of the research. This exercise resulted in farmers and researcher co-learning about the ways in which knowledge integration can be done and provided important insights into cultural elements that otherwise wouldn't have been possible to be verified and understood. This approach contributed to the argument of (Mzobe, 2022) on the need for indigenous people to be active participants of scientific research.

Diemers' (1999) theory of knowledge production argues that co-production should be based on the principles of mutual comprehension, cross-cultural contextualization and respectful valuation. However, this research found that in practice many of the current policies and research work fail to do this (Dhungana et al., 2023b). To minimize this, the researcher took the necessary steps to recognise her own in-built assumptions around society-nature relations following Rudy and White's (2014, p.129) ideas in relation to conducting transdisciplinary research noting that "hybrid understandings of society-

nature relations is important in transdisciplinary research as this provides with wider views of the different notions of nature present within different societies”. In doing this, it is always important to take the time to reflect deeply on the role of researchers as outsiders when completing studies similar as the present one.

Transnational research, especially in the context of indigenous territories comes with a high level of responsibility and ethics that should always be considered. Accessing these territories required special ethical mechanisms to be put in place (Chapter 3, Section 3.2) that are not always considered by in-country agencies and that should always be prioritised. It is important to proceed with caution when working in areas where different stakeholders are involved, as different points of views might emerge.

As with all research there were other challenges that were faced, but were overcome through the exploration of other ways of knowledge-co production and that should be considered in future studies. For example, transnational research was challenging during Covid-19 when borders were closed and forced the original research plan to be adapted meaning that it was only possible to obtain limited information in a reduced amount of time. The research was able to train young members of the communities where this research took place to collect data that otherwise wouldn't have been available given the restrictions faced.

This strategy allowed access to more detailed information, but in doing the work these trainees needed to get familiar with data collection protocols and ethics which are yet not as common in Mexico's formal education as in UK, as expressed by trainees during the research. Verification in the field by the researcher was needed to make sure these protocols were followed properly by trainees and to avoid any conflict of interest given the familiarity of trainees with different members of the milperos community since their own parents were also farmers.

Results can only be applied to the sampled elements and further research should be done to extend the sample size and include also other views and narratives from other members of the Maya Yucatec community such as those from women and youths. Beyond the size of the study sample the information collected provides new insights not fully explored within these indigenous communities in relation to the impact of new challenges and their adaptive capacity and the contributions made, and information collected was beneficial for both communities and researchers. The information presented should be considered

as a baseline for future research as important aspects could be used for studies conducted in other indigenous territories.

7.5.2. Farmers' Responses to Transnational Scientific Research

Farmers' level of trust, familiarity and open communication throughout the research process were essential as this allowed the main researcher to collect reliable data and to place herself (myself) as a learner about other ways of knowing and better understanding farmers perspectives. In doing so, a gatekeeper was needed in some communities (to make sure local governance and community protocols were respected (Chapter 3, Section 3.6.2.1).

Farmers responses to this approach were positive, and contributed to the argument from Whyte (2020, p. 3) on the need to build relationships based on “consent, trust, accountability and reciprocity” since this is an essential part of indigenous people's values and worldviews and of the epistemology of indigenous science. This process, although achieved, was challenging as in some communities there were members who portrayed a sense of mistrust of any form of research or collaboration when documenting perceptions around the use of knowledge systems in the research areas based on past experiences.

Ethical procedures (informed consent, copies of project proposal, long-distance continued communication) which appear not to be common within current local collaborators, provided farmers with a sense of trust towards the research. In addition, the co-creation of knowledge and materials which were later freely distributed amongst community members and their active involvement in knowledge exchange workshops were highly valued by farmers as a reciprocal way of collaborating and perceived as a form of respect towards indigenous values.

In both Mexico and Belize, participants perceived the knowledge exchange initiative (See Chapter 3; Section 3.8.3) as positive and highlighted as beneficial based on anonymous feedback received from the farmers at the end of the sessions. Farmers shared experience of climate change with their peers both in Mexico and Belize provided them with a sense of familiarity and trust which they acknowledged is generally lacking from current collaborations with government agencies and other research entities. They suggested this type of knowledge exchange should be prioritised by graduate students and researchers wanting to collaborate with them. It also highlighted that although beneficial, these

studies can sometimes cause disputes among local groups if not selected to participate, but that having previously worked with other academic institutions, they are aware of the financial implications and restrictions on being able to involve more people in a research study.

Suggestions from those involved in this research to minimize these challenges included expanding the duration of the research, having more community meetings (although at the time of the research this was not possible due to Covid-19 regulations) and being aware of any internal disputes among local groups to try to minimize impacts. They acknowledged that individualism is more commonly seen now at the community level and that there will always be those who will complain even if the research is beneficial, but that this aspect is not restricted to research but a common response to any type of engagement with external agencies.

In conducting this type of research, it is also important to be inclusive of women and young people but also of the cultural norms of the local communities (which in some communities still prevent women from taking part in these activities). Efforts to invite women to join these exchanges was made when possible and permitted according to the cultural norms, but none of them accepted as *milpa* continues to be seen for the most part as a “male activity”. However, through the research women who were interviewed and who are now planting *milpa* also suggested ways in which women could be included in future learning exchanges, including a gender approach to *milpa* (women only related activities) and which should be considered in future studies.

An aspect that although was not originally considered as part of the research but unexpectedly needed due to Covid-19, was the involvement of young students in data collection (See Chapter 3). This involvement provided important insights around the differences in perspectives between younger and older people in relation to climate change and agriculture particularly since the youths involved were also children of farmers (not involved in this research to avoid any bias) who have had access to formal education in disciplines related to the environment and agriculture. Involvement of youth was well perceived by farmers as the capacities learned through this research were transferred to family and friends in the community and they also got to learn indirectly about topics of interest such as soil health.

Intergenerational knowledge transmission is a relevant aspect of indigenous knowledge and suggestions on including this aspect in future studies when researching *milpa* were also given by farmers as they expressed their interest in learning about the perception of younger generations to develop community mechanisms that can help them to promote the system and avoid their traditional systems disappearing. This is a relevant point since research conducted in remote communities in Alaska around how different generations perceived climate change have shown that generational perceptions are key for assessing community's vulnerability and resilience and crucial when developing climate change adaptation strategies (Herman-Mercer et al., 2016).

Another key aspect resulting from this research is related to the strategies of autonomy and resilience that are part of farmer's adaptive capacity, and which are applied not only to challenges related to environmental risks such as climate change and food insecurity, but also to their social networks and relationships with external agents and collaborators. During the research it was observed that farmers who are given the autonomy to talk about their own experience and knowledge around a particular issue (e.g. climate change) when the approach from a researcher is as a learner rather than an "expert" and when information is shared through beneficial material or experiences (e.g. co-creation of calendars and boardgames, exchange visits) were more open to continue collaborating.

Building capacity of farmers while conducting data collection rather than just being considered as a temporary "source of information", also contributed to generating an environment of trust. During the soil sample collection (Chapter 3, Section 3.8.2.1) farmers were taught basic research processes that they express interest in. For example, they were taught how to take GPS coordinates of their plots and later they got printed copies of the mapped areas. Similarly, mini workshops around soil, using information analysed from their own plots, to explain basic concepts of soil health such as organic matter and pH (See Chapter 5; Section 5.4) were also well received.

In doing all the activities mentioned above, there should be also an acknowledgement that not every project can do this as funds for academic research are often limited and sometimes restricted to specific activities, thus more financial support should be allocated within research projects to be able to put in place similar approaches.

Researchers need to reinforce and strengthen the principles reciprocity, trust and accountability in collaborations when working with indigenous communities (Hill et al.,

2020) and situate themselves also as learners. This reinforces the argument of Nursey-Bray et al. (2020, p. 148) of the need for learners (e.g. reseachers and external agents) of “adapting to ways of doing, seeing and being in practice” as this can also benefit inter-epistemic integration.

In the next and last chapter (Chapter 8) a summary of the key findings will be discussed and the implications of these for traditional agriculture in the face of climate change.

CHAPTER 8 CONCLUSION

The research presented in this thesis is a novel approach to integrating physical and human geography in the context of climate change adaptation by indigenous peoples within traditional agricultural systems. This thesis has made academic contributions and findings with important implications for future research. Findings have provided better insights around the relevance of indigenous knowledge systems in climate change adaptation.

8.1. Research Context

Maya Yucatec peoples have historically been dependent on rainfed agriculture, particularly in the *milpa* system. Although there is a large amount of literature that has documented the changes in the *milpa* system, limited studies have focused on understanding the impacts of climate change in traditional agricultural systems in relation to the use and adaptation of indigenous knowledge systems. The aim of the present research was to document and understand the views, experiences and capacities of Maya Yucatec farmers in Mexico and Belize used to cope with the effects of climate change in the *milpa* system and the role of indigenous knowledge in this coping capacity.

In doing these four main objectives were established:

- a. Understand the dynamic process of change in *milpa* management and how this affects the mechanisms by which indigenous communities use and adapt knowledge systems when building resilience to climate change (Chapter 4)
- b. Document changes in social and environmental conditions (by mirroring farmers' knowledge with empirical data in relation to soil and microclimates) across different *milpa* systems and how they shape farmers' priorities, perceptions, knowledge systems and adaptation strategies (Chapters 5 and 6)
- c. Identify the types of knowledge that Maya Yucatec farmers in Mexico and Belize associate with the *milpa* system in small-scale farms and their role and priority in climate change adaptation (Chapters 4, 5 and 6)
- d. Identify key informational intersections between indigenous and scientific knowledge in order to describe the potential advantages and challenges of

indigenous knowledge in climate change adaptation strategies at a local level (Chapter 7).

8.2. Key research findings

The present study revealed that Maya farmers in Belize and Mexico, although sharing a similar ethnicity, cultural background, environmental conditions and livelihood patterns, have remarkably different individual relationships with the *milpa* system (Chapter 4). This research confirmed that although *milpa* in both countries is considered a modern biocultural food system, the influence of site-specific factors, interlinked with external factors, has shaped their farming priorities toward this system (Dedrick et al., 2023; Kodirekkala, 2017). This has indirectly shaped their adaptive capacity in the face of challenges such as with climate change, but it has also shaped their knowledge systems associated with this food system (Objective 1).

Findings from this research showed that the transformation process of *milpa* agriculture has been different in each country, shaped by different factors but rooted in similar historical processes (Dedrick et al., 2023). In Mexico transformation has been shaped by social and cultural elements and networks, dependant on local inputs and rooted in a historical mechanism of resistance to dominant power relations inherited from colonial times (Vázquez González et al., 2018b). In Belize the transformation process of *milpa* has been shaped by market demands, dependence for the most part on external outputs and rooted in colonial practices (Objective 1; Bolland, 2003; Vázquez González et al., 2018).

As with other indigenous agricultural systems, *milpa* has been the subject of multiple adaptation processes, however these are not new, as Maya Yucatec people have been adapting in multiple ways for millennia (Metcalf et al., 2020; Nursey-Bray et al., 2020). To understand how adaptation is built in the same ethnic group, this study prioritised the understanding of a situated knowledge (Maya Yucatec knowledge) and its usefulness and integration with other knowledges (scientific/technical) within the scope of agricultural experience to explore the adaptation process to the impacts of climate change in traditional *milpa*. Results from this study found that in the same indigenous group (Maya Yucatec) the active use of indigenous knowledge can vary significantly and thus its capacity to be regenerated, renewed and adapted can also be different (Objective 2).

The research also showed that in Mexico and Belize *milpa* farmers' process of knowledge use and adaptation has been shaped differently and is based on the depth of attachment and connection to nature (*monte*), to food, to their land as well as to cultural lives, values, ethics and worldviews (Nurse-Bray et al., 2020). These attachments are limited to local biophysical conditions and to local social networks which can also shape how knowledge is used and adapted (Objective 3).

Data from this research suggest that modern Yucatec societies in Mexico and Belize use a combination of indigenous knowledge and modern science and technology in their agricultural systems to adapt and build resilience to climate change, but knowledge integration is occurring in contexts of inequality (Camacho-Villa et al., 2021; Objective 3). Despite limited access to scientific methods and resources related to climate and soil, Maya Yucatec people are holders of a unique human capital of weather and soil which they rely on for developing their own adaptation and resilience processes. Similarly, there are remarkable differences on how these knowledge systems are used and prioritised across countries. Overall, in the studied communities in Mexico, the active use of Maya Yucatec knowledge not only in agriculture but in their livelihoods, is higher compared to those studied in Belize.

Overall, the research found that the use of specific types of knowledge in agriculture is linked to their farming priorities, but also to the kind of narrative and discourses that individuals and community members are exposed to from their social networks. This has led farmers to interlink knowledges and develop new knowledge approaches (Nguyen, 2019) by shifting individual knowledge epistemologies into pluralistic ones that allow them to build better resilience to new circumstances and to uncertainty (e.g. adaptive indigenous knowledge). These key informational intersections have allowed Maya Yucatec farmers to decide which indigenous knowledge to retain and transmit, and which not, leading them to a cultural adaptation (Reyes-García et al., 2016) as this knowledge is attached to important aspects of Maya culture and social identity (Objective 4).

8.2.1 Implications for traditional agriculture and adaptation.

Findings from this research found that farmers' current vision of the *milpa* is an influencer and driver of indigenous adaptation to challenges (Chapter 4). The contemporary vision of *milpa* is rooted in historical Maya traditions and views of the *monte* and has been reshaped because of multiple stressors such as agricultural market demands, uncertainty, poverty and marginalisation, in addition to climate related stressors. When combined, environmental, social and economic stressors led farmers to experience food insecurity, loss of income, loss of crops, loss of cultural traditions which indirectly affect how *milpa* is perceived and consequently which adaptation responses are put in place. Therefore, it can be concluded that Maya Yucatec farmers are adapting *milpa* in diverse ways due also to changing social conditions in addition to environmental ones (Nurse-Bray et al., 2022).

The research also found that economic and political factors play a crucial role in farmer adaptation processes, but these aspects are often overlooked, since most of the time the focus is on social or environmental factors (Chapter 7). For Maya Yucatec farmers in Mexico and Belize these factors should be widely considered in the future given the significant differences that each country has in terms of economic and political approaches to agriculture.

In Mexico, despite the country having more well-established policies and economic treaties around agriculture such as the NAFTA, *milpa* farmers continue to be more autonomous when it comes to agriculture institutional support compared to Belizean Maya Yucatec farmers. Mexico's farmers *milpa* system are less attached to market trends and demands, but historically have had better access to agricultural credit/capital/resources/subsidies. Although these programmes have evolved since 2019 to focus in two main aspects: 1) addressing social aspects/conditions that will limit farmers development particularly for those in rural areas and 2) improving food security and food self-sufficiency. As a result, government programmes aimed at supporting agriculture in Mexico are now considered both productive and social programmes as many of them are aimed at supporting farmers to enhance their productivity, but also to improve their living standards while promoting social development in rural areas. Many of these programmes now focus particularly on supporting smallholder farmers and

indigenous communities and they are also divided according to the agricultural sector and the type of crops with a great focus on rainfed and traditional agriculture. Examples of these programmes include Programa Produccion para el Bienestar/ Production for Wellbeing Program (currently the programme with the highest coverage in the country and which benefits farmers from different crop systems including *milpa* and which considers also the diversity of climate conditions and types of soil available in the country), Programa Sembrando vida/Sowing Life Programme (focused on rescuing the countryside/traditional agricultural systems, reactivating the local economy and strengthen the social governance in local communities), Programa Bienpesca/Goodfishing Programme (support for fishermen).

In Belize, despite the limited market opportunities and limited economic development at the local, national and at a regional level, *milpas* and other agricultural systems are highly dependent on market trends (Chapter 4). This dependency underlies specific social, financial and informational barriers that can limit farmer's adaptation and include less availability of subsidies/credit/funds, lack of market outputs, limited access to agricultural extension services, limited access to reliable information, limited access to economic development and market transition. The government incentives and programmes aimed at supporting the agricultural sector in Belize are designed to enhance productivity, are focused on modernization and most of them are limited to key agricultural industries (e.g. Belize Sugar Cane Farmers Association) and tend to exclude traditional crops systems like *milpa*. Most of these support programmes consist of loans (e.g. Development Finance Corporation, credits (carbon credit programmes from the Green Climate Fund) and subsidies (e.g. Ministry of Agriculture's subsidy programmes).

For many farmers, in both countries, when trying to access these government agricultural programmes they face many social and institutional barriers leading them to look for their own resources, services and technologies to cope with challenges. In Mexico although these programmes are now shifting to support farmers with a socio-economic perspective it is important to address some of the invisible barriers that these programmes might have (e.g. available to indigenous farmers but information is online in areas with limited literacy levels or access to internet services).

According to Adger et al., (2005b) separating climate change adaptation from socio-economic changes is difficult. In the case of *milpa* adaptation strategies, these need to be thought through a broader perspective and not only from an environmental perspective. Therefore, institutional frameworks need to examine thoroughly how current supporting mechanisms can improve climate change resilience considering different factors from microclimates (like Sembrando Vida) to cultural diversity (it still doesn't seem to be clear how is it incorporated within several government mechanisms).

This is probably one of the main challenges to address, particularly in dynamic ecological-social-economic systems like *milpa*, because while adapting to climate change farmers also need to be adapting to other social and economic factors (Dang et al., 2019) making adaptation more complex. Future research around *milpa* system should focus on better understanding other non-climatic changes and human impacts that might be occurring in *milpa* as a result of climate change (such as change in levels of poverty, migration, rural degradation, etc) which have also been documented in many other traditional communities across the globe (Reyes-García et al., 2024).

8.2.2. Implications for the future of *Milpa*

One of the main factors influencing the way *milpa* is perceived is related to connection and spirituality. Farmers in both countries believe that *milpa* is part of an ethos of care and although the depth of attachment is different, this spiritual component remains active in modern *milpa* and could be one of the main reasons *milpa* continues to survive across time as it reflects a mindset of Maya Yucatec life (Chapter 4).

The physical composition of *milpa* differs between countries since they are structured for different purposes at an individual level depending on farmers' priorities. *Milpa* in Mexico and Belize continues to be present for an overall purpose: food security. There are, however, other priorities which differ by country. In Belize it is about productivity, marketing and family income, while in Mexico is about family, tradition and income (Chapter 4).

These priorities could also explain why within this study farmers perceived that the main changes that have occurred in *milpa* are related to traditions, management, environmental conditions, economy and yields. However, the transformation process of *milpa* has

occurred in a different way across Mexico and Belize (Chapter 4). *Milpas* in Mexico have undergone less transformation than those in Belize. This could be because *milpa* continues to be strongly attached to local social networks and governance processes such as their land tenure (ejido) shaped to respect self-determination and autonomy and prioritising preserving native seeds since they are aware this could also transform their culture. *Milpas* in Belize have lost some of the cultural attachment to be able to be more productive.

The way *milpa* is bio culturally perceived in contemporary Maya Yucatec societies should be considered by local agencies in each country when developing adaptation strategies which could benefit collective agency. Currently these strategies tend to be developed for the most part homogeneously, for all farmers, and could lead to maladaptation. The current local and national adaptation strategies appeared to be developed to address similar environmental threats faced by farmers in their livelihoods but have not considered farmer's priorities nor culture and knowledge.

The evidence from this study suggests that given that climate change is impacting social and cultural dynamics these contexts should also be considered when institutional support is provided to reduce climate and non-climate stressors which together are causing social inequalities and leading to increasing farmers' vulnerability (Camacho-Villa et al., 2021; Fisher, 2020).

8.2.3 Implications for climate change and Indigenous adaptation

In relation to climate change, this thesis has provided a deeper insight into how individual climate change perception, adaptation and resilience occurs in members of Maya Yucatec communities in Mexico and Belize. For these modern societies, climate change continues to be an important factor impacting human-environment conditions and their capacity to build resilience.

The study showed that there is a notion of modern Maya Yucatec peoples in Mexico and Belize around nature and an ethos of care which varies markedly. There is, however, something in common between all of them in relation to the current social-environmental crisis. Maya Yucatec people believe that climate change and the environmental crisis is the result of a rupture in the nature-society relationship (e.g. farmers and the monte;

Chapter 6). Given the influence of Christianity/Catholicism during colonial times farmers also believe climate change is a punishment from God (Jesus) for humans' sins against nature (Ford et al., 2020).

An important finding from this research is that beliefs and perceptions around climate change in both countries are mostly constructed from farmers' lived experiences, although social networks appear to be playing a significant role and shifting this construction (Wens et al., 2021). Modernization of traditional agriculture, market integration and involvement with different external organizations have also shaped their climate change awareness and consequently their climate risk and perception.

In the agricultural study areas, given the high dependence of farmers on temperature and rainfall for their livelihoods, although vulnerable to climate change, they have been actively addressing this vulnerability across time through alternative knowledge integration (e.g. AIK) of both indigenous and scientific knowledge (Chapter 6; Rarai et al., 2022).

Because of farmers' dependency on weather patterns, much indigenous knowledge in relation to climate and agriculture has focused on seasonal observations and moon phases and is interrelated with astrological cycles (Sánchez-Cortés & Chavero, 2011, 2018). This had led farmers to develop unique ways of "reading the weather", developing bioindicators, understanding micro-climate patterns and perceiving local changes based on memorised observations and evaluations across time from different past events (Chapter 6; Roué, 2018; Weber, 2010). These results strengthen the idea that indigenous knowledge can provide place-based information not always available to science (Nursey-Bray et al., 2022).

The perceived changes in micro-climate patterns described by farmers (given the lack of accessibility to instrumental records and accurate forecasts) have led Maya farmers to make more localised decisions about farming and develop local-social adaptation strategies to both changing environmental and social conditions (See Chapter 6; Section 6.6.2).

These findings support the idea that indigenous resilience is built by using "the strength of past events to adjust to future" (Sakakibara, 2018, p. 267) and that indigenous knowledge is "a source of localised wisdom" (Makondo & Thomas, 2018, p. 73). Place-based knowledge, as with the Maya Yucatec, is useful to understand changes in

microenvironments, particularly in countries lacking local meteorological systems at the community level like Mexico and Belize. Investment in meteorological equipment would be beneficial for the studied communities to complement and interlink knowledges for better adaptation strategies particularly in rainfed systems like *milpa*.

The impact of 2019 drought and 2020 tropical storms and hurricanes in the study area supported the argument from Sakakibara (2018) on how indigenous resilience is built (see above) since the majority of the farmers who took part in this study assessed these two events as some of the most impactful in their farming lives. This was a shared perception of farmers from both countries but also amongst all farmers regardless of their age.

The results of this study indicate that the main impact of climate change on Maya Yucatec communities in both countries appears to be loss of traditional crop types and loss of native seeds. As a result, the main adaptation strategy currently used is changing or adjusting planting dates (Briones, 2018). Other adaptation strategies have been implemented, but they differ in the frequency of usage and include cultivating multiple crops or changing crop varieties (Briones, 2018; Harvey et al., 2018), using different water irrigation systems and increasing the use of herbicides, fungicides, pesticides and fertilizers.

Adaptation strategies were found to be driven by government or non-government/research organizations and by farmers' knowledge or experiential learning and focused on crops, water, soil, technology and use of inputs (biological or chemical). These findings complement those of earlier studies for Latin America (Boillat & Berkes, 2013; Briones, 2018; Harvey et al., 2018; Mardero et al., 2015; Metcalfe et al., 2020; Sánchez-Cortés & Chavero, 2011, 2018) and worldwide in countries highly dependent in traditional agriculture (Belay et al., 2017; Gbetibouo, 2011; Kassem et al., 2019; Mogomotsi et al., 2020; Nzeadibe et al., 2012).

One key highlight is that adaptation to climate change in Maya Yucatec peoples is not homogenous, confirming the findings of Metcalfe et al. (2020). Results from this study furthered contributions to the literature since it showed that adaptation in the same indigenous group is autonomous (Rahman et al., 2021) and appears to be based on four specific factors: a) farmer's priorities; b) worldviews and beliefs; c) climate change

awareness/perception of environmental conditions and d) social networks. More information from a larger sample size would help to establish a greater degree of accuracy on this matter, since the study was limited to a small number of case studies and a relatively small sample in the studied communities. Despite its limitations the study certainly adds to the understanding of how adaptation and resilience is built in contemporary indigenous societies and the implications for local climate policy.

One of the more significant findings to emerge from this study is that climate change is not only impacting Maya Yucatec agricultural food systems and livelihoods, but also local social structures, culture and knowledge systems.

This study offers some insights into indigeneity and climate change important for the literature:

- Given the socio-ecological ties that Maya Yucatec people continue to have culturally and spiritually with nature in their daily lives (regardless of their depth of attachment), changes in weather patterns and lack of reliable information and understanding about microenvironments, is leading to abandonment of cultural practices associated with *milpa* farming.
- Maya Yucatec characterization of climate in relation to rainfall and temperature is more focused on duration rather than amount (Sánchez-Cortés & Chavero, 2011) but their agricultural activities are shaped around both duration and amount. Their knowledge of how they experience variation is similar to that measured through instrumental meteorological systems and should be considered for future studies around microclimates, particularly in areas with limited technical monitoring equipment.
- Contemporary asymmetric power-knowledge relations and social networks are a major factor influencing cultural adaptation in Mexico and Belize. These inequalities in power relations, through established partnerships with local government and research institutions have historically led Maya Yucatec farmers to develop alternative adaptation responses (Wheeler et al., 2020). In Belize, this is more evident given that national agricultural discourses are constructed towards the idea that farmers need to focus on productivity and increasing the local economy, but with little consideration of the farmer's own priorities, or to preserving cultural identity and indigenous knowledge. This narrative appears to have its roots in

colonial structures and attitudes which might continue to be embedded in many aspects of Belizean culture and could limit farmers' adaptation.

- Currently the climate change adaptation strategies and policies put in place continue to follow a top-down approach. There is, therefore, a need to shift this approach so that indigenous values, ways of life, technical capacity and knowledge systems are considered, and for indigenous peoples to be included in local policy formulation (Datta & Chapola, 2017; Nursey-Bray et al., 2022).
- Local climate change adaptation strategies promoted by government, private and research institutions in Mexico and Belize need to ensure that such strategies are connected across social, cultural and environmental contexts since all are interlinked.
- Findings from this study extended the information documented in other regions in the world who have argued that engaging indigenous knowledges and ways of being based on connection, reciprocity, and ethical relationships (e.g. indigenous sacred relationships with nature) could reshape environmental management and could also help with the power-knowledge structures that has dominated globally (Kealiikanakaoleohailani & Giardina, 2016; Muller et al., 2019).

The insights gained from this study may be of assistance to local governments, agencies and research centres looking for better knowledge collaborations that can help to reduce involuntary cultural adaptation and build better just and equitable adaptation options and policies to climate impacts. This is particularly important since the findings reported in this research shed new light on how climate change is destabilising the certainty of the indigenous knowledge in relation to weather patterns and the implication of this in adaptation and resilience processes.

Results from this research also revealed that beyond local climate change adaptation, lack of interlinked policies and economic development measures in Maya Yucatec communities from local governments appeared to reinforce farmer's vulnerability. Further research is, however, needed to explore the context and root causes in which vulnerability occurs within these indigenous communities.

8.2.4. Implications for soil and Indigenous Adaptation

Results documented through this research showed that soils in the studied communities in Mexico and Belize are being impacted by changes in climate amongst other things. Although soil is essential for agriculture and many land management practices and adaptation strategies in *milpa* involve soil quality, there is a remarkable lack of direct monitoring of soil health. However, this research also found that farmers have developed innate skills to assess soil characteristics and have developed indigenous identification keys that have been useful to measure specific soil properties.

The research found, through local soil characterisation, how indigenous knowledge is developed, validated and adapted. Although the farmers that took part in this research have had limited exposure to scientific knowledge of soil, their daily direct observations and management of the land have allowed them to develop extensive knowledge of texture, properties (including colour) and usefulness for agriculture (Chapter 5). As a result, they possess a unique local human capital of soil that appears to have been dismissed by local agencies despite their relevance. Because of this knowledge developed through experience, farmers have also been able to decide which soil knowledge should be prioritised and used to address any challenges related to soil functionality.

In areas with very limited scientific characterisation of soils like in Belize, this indigenous knowledge is of great value and should be used to update national records. In the case of Mexico indigenous characterizations of local soils have already been documented (Bautista & Zinck, 2010) and should continue to be integrated into the current scientific characterisations available and shared with local communities as this will allow better management of microenvironments particularly in challenging times which can also promote collective agency.

As climate change progresses and giving the impact of it on soil, in the long term some farmer's current management strategies could potentially limit their capacity to continue adapting and to plant specific crops that are an essential part of their livelihoods and culture, while threatening food security. Therefore, it is recommended that local government and institutions working directly with farmers (e.g MoA, Sembrando Vida Agricultural Programme) develop better mechanisms to monitor soil health that are affordable for farmers and can provide them with additional scientific information that can be used together with their knowledge for better land management. As Camacho-

Villa et al. (2021, p. 13) stated, in studying climate change adaptation in traditional agricultural systems it is important that any future agricultural development interventions “are sensitive to the cultural dimension of farming” since any potential loss of cultural elements of Maya Yucatec societies will represent a cultural harm given the links of Maya Yucatec local microenvironments to governance, land rights, land tenure and identity.

8.2.5 Implications for knowledge-based adaptation (Indigenous and Scientific)

In analysing the role of indigenous knowledge in climate change adaptation, this study found that differences in the process of change and in the channels of knowledge transfer are occurring in Mexico and Belize (Okui et al., 2021). Evidence from this study shows that Maya Yucatec indigenous knowledge has been developed and transmitted through completely different frameworks across each country. Farmers in Belize are transitioning from indigenous based knowledge to adaptive indigenous knowledge (AIK) strategies influenced by site-specific drivers (Chapter 7). Although less evident, some farmers in Mexico are also transitioning to this knowledge framework, but for the most part their historical knowledge framework is persisting.

Despite its exploratory nature and although the current study is based on a small sample of participants, the findings suggest the following in relation to knowledge systems adaptation in indigenous communities:

- Access to climate knowledge is generally low among indigenous peoples in Belize and Mexico, with only few members accessing climate information from local agencies.
- Inadequate knowledge integration and transfer related to climate science has led Maya Yucatec farmers to continue relying on experiential and family learning processes to overcome climate change impacts and has led them to reconstruct and create new knowledge approaches or combine knowledge systems (epistemological pluralism).
- Dismissal of indigenous knowledge by local agencies has led Maya Yucatec farmers in Mexico and Belize to undergo a process of involuntary cultural adaptation. This cultural adaptation is being shaped differently in each country and influenced by different internal and external factors. However, it appears to be that contemporary and unequal power-knowledge relations and social networks are a major factor

influencing cultural adaptation in Mexico and Belize (Wheeler et al., 2020). Politics and local policies and government institutional frameworks also appear to be playing a crucial role in farmer's adaptation.

- Cultural adaptation has indirectly re-shaped their decision making, their ways of being and acting and their own adaptation responses to known and new challenges, consequently, influencing the way *milpa* is perceived and managed.
- Results from this research showed that modern Maya Yucatec knowledge, is a historical knowledge adapted as a result of Spanish and British post-colonial influence on local inhabitants and their everyday livelihoods (Inoue & Moreira, 2016).
- Indigenous knowledge continues to be important in the studied communities in Mexico and Belize, but the frequency and use of this knowledge is changing based on the farmers' priorities.
- The use of indigenous knowledge is also indirect evidence of the relationship of each farmer with the *monte* (regardless of how deep that relationship is).

8.3. Shortcomings and opportunities for future research

The major limitation of this study was the sample size due to restrictions faced during the development of this research as a result of Covid-19. Despite its limitation this study offers valuable insights into the impact of climate change on knowledge systems and culture which has been less studied in climate science. The sample size makes these findings less generalisable to all the Maya Yucatec society, however this study has been one of the first attempts in the region to examine the role of knowledge systems in adaptation which lays the groundwork for future extensive research.

The present study has gone some way towards enhancing our understanding of microenvironments and the potential of traditional agricultural systems. In relation to climate data the study was limited by the absence of crucial meteorological data from the studied communities due to failures of installed weather stations during fieldwork and the lack of historical data. Notwithstanding these limitations, the study demonstrated the importance of local indigenous knowledge when scientific data are not available to understand changes in local weather conditions. Future studies should focus on building assessments that include the means of verification using both indigenous and scientific

knowledges and that are easy to manage by both indigenous and scientific communities to collate and interlink crucial data.

Historically, *milpa* has been a male dominated activity. However, this research included the views of some women that are farming *milpa* in relation to climate change adaptation and use of knowledge as part of the analysis. Although gender was not directly considered for this study, further research should focus on analysing the use and adaption of indigenous knowledge in the context of climate change with a gender perspective (Alonso-Epelde et al., 2024). Maya Yucatec women are also holders of important knowledge of *milpa*, but often overlooked, therefore assessing the differences in type, access, use, transmission and preservation will be of great value to complement the findings from this research and will also help to address power dynamics historically embedded in *milpa* farming.

Finally, results from this research offer a solid basis and argument for re-thinking environmental studies and climate change policy. Efforts to integrate both indigenous and scientific knowledge will continue to fail if a methodological division in terms of consistency continue to be (Camacho-Villa et al., 2021).

The present study adds to the growing body of research that suggests that indigenous knowledge systems and modern knowledge can be integrated in climate studies through a pluriverse approach and embracing epistemological diversity assumed (Amo-Agyemang, 2021; Camacho-Villa et al., 2021; Rarai et al., 2022). Therefore, more efforts are needed in climate science to engage with plural epistemologies (multiple ways of knowing) in the context of climate change adaptation research.

Re-thinking and re-evaluating different knowledge systems and shifting how knowledge integration is done, can help to address historical dismissal, historic injustices and unequal power relations towards indigenous knowledge in climate change science and policy, both in theory and practice, by being culturally-situated, equitable, diverse and inclusive for all those impacted by climate change.

Each of the Maya Yucatec communities included in this research has its own characteristics, despite sharing a similar cultural background and each of these characteristics has a level of importance. The exploration of different social, environmental and cultural characteristics when interlinked is crucial to understand how adaptation occurs in complex social-ecological systems within indigenous groups.

Cultural factors which are often overlooked, such as indigenous knowledge, can provide crucial information to understand how resilience is built and should receive considerable attention when developing in-country adaptation strategies. Despite having been impacted by climate change and other challenges, *milpa* continue to be one of the most important food systems in indigenous communities in Mexico and Belize.

The resilience of a complex socioecological system such as the *milpa* has been built through many autonomous adaptation processes built through collective knowledges and enhanced and implemented by farmers who still practice it. In making adaptations, inter-epistemic approaches have been put in place by farmers and different knowledge systems have played a crucial role in adaptation, helping to overcome historical and current limitations and barriers. The challenges faced through this research helped to indirectly show that indigenous knowledge can help address many gaps still present in modern science and should open the door for a continued incorporation of it in academic research. Similarly, this research illustrates that doing modern science incorporating epistemological pluralistic approaches is possible and should be replicated by other researchers. Such an approach does offer new insights into understanding how different groups (here Maya Yucatec farmers) perceive and respond to climate change, offering insights into improving future coping strategies.

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Appendices

Appendix 1 Research Ethics Form

School of Geography
Research ethics checklist for staff and research students
(last updated July 2018)
[strongly informed by ESRC (2010) Framework for Research Ethics]

This form must be completed for **all** research projects, research assignments or dissertations which are conducted within the School. You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 2 and/or 3, 4, 5, 6. Ticking a shaded box in Sections 2, 3, 4, 5 or 6 requires further action by the researcher. Two things need to be stressed.

- Ticking one or more shaded boxes does **not** mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does **not** mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project - should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

Research Context

Through the General Data Protection Regulation (GDPR) that came into force in May 2018 the University is required to inform every individual whose personal data we process exactly what we are doing with their data, the legal basis for it, who we share it with, how long it is kept for and what that individual's rights are with respect to the personal data that we hold. This information needs to be contained in a Privacy Notice that must be provided to every individual whose personal data we use in research studies. Further details on the GDPR are available at the University's GDPR workspace:
<http://workspace.nottingham.ac.uk/pages/viewpage.action?spaceKey=GDPR&title=General+Data+Protection+Regulation+%28GDPR%29+Home> or ask your supervisor

In relation to General Data Protection Regulation (GDPR)

		Yes	No
1	I confirm that I am aware of the GDPR and the proposed work will be compatible with it	X	
2	The research to be undertaken is in the public interest	X	
3	If the project involves participants they will be directed to an appropriate privacy notice	X	

If the answer to any of the above is 'no' further details should be provided in section 7.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher (in CAPITALS): KARLA GABRIELA HERNANDEZ AGUILAR

1.2: Status: ☐ Staff
☒ Postgraduate research student

1.3: Email address: karla.hernandezaguilar@nottingham.ac.uk

1.4: Names of other project members (if applicable): Prof. Roger Medina, Dr. Birgit Schmook

1.5: Name of supervisors (if applicable): Prof. Sarah Metcalfe, Dr. Franziska Schrod, Dr. Zinnia Gonzalez

1 August 2018

School of Geography
Research ethics checklist for staff and research students
(last updated July 2018)
[strongly informed by ESRC (2010) *Framework for Research Ethics*]

This form must be completed for **all** research projects, research assignments or dissertations which are conducted within the School. You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 2 and/or 3, 4, 5, 6. Ticking a shaded box in Sections 2, 3, 4, 5 or 6 requires further action by the researcher. Two things need to be stressed.

- Ticking one or more shaded boxes does **not** mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does **not** mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project - should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

Research Context

Through the General Data Protection Regulation (GDPR) that came into force in May 2018 the University is required to inform every individual whose personal data we process exactly what we are doing with their data, the legal basis for it, who we share it with, how long it is kept for and what that individual's rights are with respect to the personal data that we hold. This information needs to be contained in a Privacy Notice that must be provided to every individual whose personal data we use in research studies. Further details on the GDPR are available at the University's GDPR workspace:

<http://workspace.nottingham.ac.uk/pages/viewpage.action?spaceKey=GDPR&title=General+Data+Protection+Regulation+%28GDPR%29+Home> or ask your supervisor

In relation to General Data Protection Regulation (GDPR)

		Yes	No
1	I confirm that I am aware of the GDPR and the proposed work will be compatible with it	X	
2	The research to be undertaken is in the public interest	X	
3	If the project involves participants they will be directed to an appropriate privacy notice	X	

If the answer to any of the above is 'no' further details should be provided in section 7.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher (in CAPITALS): KARLA GABRIELA HERNANDEZ AGUILAR

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1.5: Name of supervisors (if applicable): Prof. Sarah Metcalfe, Dr. Franziska SchrodT, Dr. Zinnia Gonzalez

1 August 2018

The Research Ethics Panel

- ☐ agrees that the research can go ahead as planned

- ☐ requests further information and/or amendments to the research protocol (see details below)

School REO..... *G. body* Date ...19/12/19.....

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Checklist for Database use: 01/06/2022

Appendix 3. Survey (Spanish and English Version)



University of
Nottingham
UK | CHINA | MALAYSIA

ENCUESTA

Comprender los microambientes y el potencial de los sistemas agrícolas tradicionales en un clima cambiante en México y Belice

Página de información

Querido Participante,

Está invitado a participar en esta encuesta que examina el uso de conocimientos y estrategias de adaptación en el sistema de la *milpa*.

¿De qué se trata el proyecto?

La Universidad de Nottingham y Future Food Beacon están llevando a cabo este proyecto de investigación. El propósito de este estudio es desarrollar una comprensión profunda del uso y adaptación de los conocimientos (principalmente las costumbres y saberes antiguos) por parte de los agricultores en sus sistemas agrícolas (*milpas*) y en sus estrategias de adaptación ante el cambio en el clima y otras dificultades.

¿Quién está llevando a cabo el proyecto?

Este proyecto está siendo realizado por Karla G. Hernandez-Aguilar (estudiante de doctorado) y miembros de la Universidad de Nottingham (UoN)/ ECOSUR / UADY: Prof. Sarah Metcalfe, Dra. Franziska Schrodtt, Dra. Zinnia Gonzalez-Carranza, Dra. Birgit Schmook y Prof. Roger Medina .

¿Por qué lo invitamos a participar?

Se le ha invitado a participar en esta investigación porque es un agricultor maya que actualmente practica la *milpa*.

¿A que lo estamos invitando?

Se le invita a responder las siguientes preguntas lo mejor que pueda. Todas sus respuestas son confidenciales y la información recopilada en esta encuesta es anónima. La información se juntará con las respuestas de otros agricultores para su análisis y se utilizará solo con fines académicos.

¿Cuánto tiempo llevará su participación en esta encuesta?

La encuesta tomará de 45 a 60 minutos.

¿Existe algún riesgo asociado por participar en este proyecto?

El proyecto no tiene riesgos previsibles.

¿Cuáles son los beneficios potenciales del proyecto de investigación?

El conocimiento/información obtenido de este proyecto puede ayudar a otros investigadores, agricultores y partes interesadas involucradas en actividades agrícolas en el diseño de futuros

modelos y estrategias de investigación para apoyar a los pequeños agricultores frente a un clima cambiante.

¿Puede retirarse del proyecto?

La participación es voluntaria. Si acepta participar, puede retirarse del estudio en cualquier momento.

¿Qué pasará con su información?

La información y los datos recopilados del estudio se gestionarán y almacenarán en formato electrónico no identificable (anónimo) durante al menos 7 años y se mantendrán confidenciales en una base de datos segura. La información confidencial que proporcione solo será accesible para los investigadores a cargo de este proyecto. Los resultados se publicarán potencialmente en revistas científicas, así como en conferencias nacionales y / o internacionales, medios locales y reuniones comunitarias.

¿Con quién se puede comunicar si tiene preguntas, quejas o inquietudes sobre el proyecto?

El estudio ha sido aprobado por el Comité de Ética en la Investigación de la Escuela de Geografía de la Universidad de Nottingham. Si tiene preguntas o inquietudes asociadas con los aspectos prácticos de su participación en el proyecto o desea plantear una inquietud o queja sobre el proyecto, puede dirigirse a la Investigadora Principal Prof. Sarah Metcalfe por correo electrónico sarah.metcalfe@nottingham.ac.uk

Las quejas o inquietudes se tratarán de manera confidencial y se investigarán a fondo. Se le informará del resultado.

FORMULARIO DE CONSENTIMIENTO

Al marcar todas las casillas, da su consentimiento para participar en este estudio:

- ☐ He leído la página de información. Acepto participar en el proyecto de investigación titulado "Comprender los microambientes y el potencial de los sistemas agrícolas tradicionales en un clima cambiante en México y Belice" y las actividades descritas. Mi consentimiento se da libremente.
- ☐ El investigador y/o asistente de campo me ha explicado satisfactoriamente cuál es el propósito del proyecto y cómo me afecta, incluidos los riesgos potenciales. He tenido la oportunidad de hacer cualquier pregunta que pueda tener sobre el proyecto y mi participación. También se ha explicado que mi participación puede no tener ningún beneficio directo para mí.
- ☐ Entiendo que mi participación es anónima y que puedo retirarme en cualquier momento.
- ☐ Me han informado que los datos resultantes del proyecto pueden ser publicados en artículos de revistas o utilizados en presentaciones de conferencias o medios locales y comunitarios. No seré identificado (anonimato) en los materiales publicados.
- ☐ Entiendo que los datos de investigación recopilados en este proyecto pueden ser utilizados por los investigadores en futuros proyectos de investigación estrechamente relacionados con este proyecto. No se compartirá ni utilizará ninguna información que pueda identificarme (anonimato).
- ☐ Entiendo que mi información solo se divulgará de acuerdo con el consentimiento proporcionado.

Fecha

QUESTIONNAIRE SURVEY

Understanding microenvironments and the potential of traditional farming systems in a changing climate in Mexico and Belize

Information Page

Dear Participant,

You are invited to take part in this survey, which examines the use of knowledge and adaptation strategies in the *milpa* system.

What is the project about?

The University of Nottingham and the Future Food Beacon are conducting this research project. The purpose of this study is to develop an in-depth understanding of the use and adaptation of knowledge (primarily traditional ecological knowledge) by indigenous farmers in their agricultural systems (*milpas*) and in their adaptation strategies.

Who is undertaking the project?

This project is being conducted by Karla G. Hernandez-Aguilar (PhD Student) and UoN/ECOSUR/UADY members: Prof. Sarah Metcalfe, Dr. Franziska Schrodte, Dr. Zinnia Gonzalez-Carranza, Dr. Birgit Schmook and Prof. Roger Medina.

Why are you being invited to participate?

You have been invited to participate in this research because you are a small-scale Maya farmer currently practicing *milpa*.

What are you being invited to do?

You are invited to answer the following questions to the best of your knowledge. All your responses are confidential, and the information gathered in this survey is anonymous. Information will be collected with other respondents' responses for analysis and will be used only for academic purposes.

How much time will your involvement in the project take?

The survey will take from 45 to 60 minutes.

Are there any risks associated from participating in this project?

The project has no foreseeable risks.

What are the potential benefits of the research project?

The knowledge gained from this project may potentially assist other researchers and agricultural stakeholders in designing future research models and strategies to support small-scale farmers in the face of a changing climate.

Can you withdraw from the project?

Participation is voluntary. If you agree to participate, you can withdraw from the study at any time.

What will happen to your information?

Information and data collected from the study will be managed and stored in non-identifiable (anonymous), electronic form for at least 7 years and remain confidential in a secure database. The information you provide will only be accessible to the researchers in charge of this project. The data will be potentially published in scientific journals as well as in national and/or international conference presentations. Individuals will NOT be identified by name in any publication/presentation. Your information will only be used as described above and it will only be disclosed according to the consent provided.

Whom do you contact if you have questions, complaints or concerns about the project?

The study has been approved by the School of Geography Research Ethics Committee at the University of Nottingham. If you have questions or concerns associated with the practical aspects of your participation in the project or wish to raise a concern or complaint about the project, you can approach the Principal Investigator Prof. Sarah Metcalfe by email sarah.metcalfe@nottingham.ac.uk

Complaints or concerns will be treated confidentially and fully investigated. You will be informed of the outcome.

CONSENT FORM

By checking all the boxes you consent to take part on this study:

- ☐ I have read the Information Page. I agree to take part in the research project entitled “Understanding microenvironments and the potential of traditional farming systems in a changing climate in Mexico and Belize” and activities outlined. My consent is given freely.
- ☐ I have been explained to my satisfaction by the researcher what the purpose of the project is and how it affects me, including the potential risks. I have had the opportunity to ask any questions I may have about the project and my participation. It has also been explained that my involvement may not have any benefit to me.
- ☐ I understand that my participation is anonymous and that I can withdraw at any time.
- ☐ I have been informed that the data resulting of the project may be published in journal articles or used in conference presentations. I will not be identified in published materials.
- ☐ I understand research data collected in this project may be used by the researchers in future research projects closely related to this project. No information that could identify me will be shared or used.
- ☐ I understand my information will only be disclosed according to the consent provided.

Date

Date: Age: Gender:	Community: Land Tenure:
Section 1 Socioeconomic	1.1. What is your main source of income? ☐ Agriculture ☐ Paid Job ☐ Family business ☐ Government Social Program (Specify which one) ☐ Other (Specify)
	1.2. For how long have you been a farmer? ☐ 1 to 10 years ☐ 11 to 20 years ☐ 20 to 30 years ☐ More than 30 years.
	1.3. What type of agriculture do you practice? ☐ Individual ☐ Community Group ☐ Government Agro-Program ☐ Research Program ☐ Family ☐ Combined (Specify)
	1.4. Which is the main destination of your yield? ☐ Self-consumption ☐ Sell ☐ Animal Feed ☐ Storage (Seeds) ☐ Other (Specify)
Section 2 Milpa Information	2.1. What other names do you use to refer to <i>milpa</i> ?

	2.2. Could you explain/describe what is a <i>milpa</i> ?
	2.3. What does the <i>milpa</i> represent to you?
Section 3 <i>Milpa</i> and Knowledge	3.1. How did you learn how to do <i>Milpa</i> ? ☐ I learned from my Dad ☐ I learned from other member of the family ☐ I learned by myself by watching others ☐ I learned from a friend or neighbour ☐ I learned through a training developed by a third party ☐ Other (Specify)
	3.2. Are the youngest members of your family learning how to do <i>milpa</i> /agriculture? ☐ Yes, all of them ☐ Yes, but only some of them ☐ Only partially learning/seasonally ☐ No
	3.3. If yes, how do young members of your family learn how to do <i>milpa</i> /agriculture? ☐ Direct observation and practicing ☐
	3.4. If no, why do they stop learning/practicing <i>milpa</i> ?
	3.5. What are some of the traditions involved/practiced as part of the <i>milpa</i> ?
	3.6. Do you still use this traditions and knowledge? ☐ Always ☐ Almost always ☐ Sometimes ☐ Almost never ☐ Never

	3.7. If always, what motivates you to keep using these traditions and knowledge?
	3.8. If never, why did you stop using these traditions?
	3.9. If never, how long ago did you stop using this traditions and knowledge? ☐ 1 to 5 years ago ☐ 6 to 10 years ago ☐ 11 to 15 years ago ☐ More than 15 years ago
	3.10. Do you consider the traditions and knowledge about <i>milpa</i> are important? Why? ☐ Yes ☐ No
	3.11. How do you think <i>milpa</i> /agriculture would be affected if this traditions and knowledge change or disappear?
	3.12. Do you think people in your community still consider important to use traditions and knowledge when doing <i>milpa</i> ? ☐ Yes, everyone ☐ Almost everyone ☐ No, anyone ☐ No, except elders ☐ No, except those who practice agriculture
	3.13. Do you think traditions around <i>milpa</i> have changed? If Yes, described how? ☐ Yes ☐ No
	3.14. Do you think there are any advantages of possessing this traditions and knowledge over those that don't have them? ☐ Yes

	☐ No
	3.15. If yes, what are some of these advantages?
	3.16. Do you think there are any disadvantages of possessing this traditions and knowledge over those that don't have them? ☐ Yes ☐ No
	3.17. If yes, what are some of these disadvantages?
	3.18. Do you think traditions and knowledge are important to scientists, stakeholders, collaborators? ☐ Always ☐ Almost always ☐ Sometimes ☐ Almost never ☐ Never
	3.19. From 1 to 5 where 1 is very important and 5 not important, how important do you think is to preserve this traditions and knowledge? ☐ 1 Very Important ☐ 2 Important ☐ 3 Neutral ☐ 4 Low Important ☐ Not important
	3.20. What is your perception in relation to all the scientific knowledge/technologies available to improve agriculture?
	3.21. Which method do you PREFER when doing <i>milpa</i> ? ☐ Traditional method

	☐ Semi-traditional (At least one stage of the <i>milpa</i> is done traditionally) ☐ Modern method (mechanized/improved varieties) ☐ A combination of traditional and modern ☐ Traditional method and own experiments ☐ Modern method and my own experiments ☐ Other (Specify)
	3.22. Can you tell me why you prefer the selected way?
	3.23. In a scale from 1 to 5 where 1 is very important and 5 Not Important, tell me how important is the <i>milpa</i> for you? ☐ 1 Very Important ☐ 2 Important ☐ 3 Neutral ☐ 4 Low Important ☐ 5 Not important
	3.24. For each of the following activities what type of knowledge you use (T= Traditional S=Scientific/Technological C= Combined E=Experiment/Trial and Error) ☐ Land preparation (T-S-C-E) ☐ Planting (T-S-C-E) ☐ Fertilization (T-S-C-E) ☐ Plague Control (T-S-C-E) ☐ Water irrigation (T-S-C-E) ☐ Harvest (T-S-C-E) ☐ Storage (T-S-C-E) ☐ Commercialization/Marketing (T-S-C-E) ☐ Adaptation to climate changes (T-S-C-E) ☐ Adaptation to unknown challenges (T-S-C-E)
	3.25. Do you think traditional knowledge (your traditions and knowledge) and scientific knowledge can be combined to improve agriculture? ☐ Yes

	☐ Somehow ☐ No ☐ I don't know
	3.26. What would be the advantages and challenges of combining your knowledge and scientific knowledge to improve agriculture? Advantages: Challenges:
	3.27. Do you have any tradition/religious practice that you use at your <i>milpa</i> to improve yield/cultivation? ☐ Yes ☐ No If yes, could you please describe which one?
	3.28. Besides agriculture, in which other aspects of your life do you use traditional knowledge? (Select all that apply) ☐ Weather forecast ☐ Family festivities ☐ Hunting ☐ Health ☐ Forestry ☐ Gardening ☐ Cooking ☐ Environmental management ☐ Other (specify)
	3.29. Considering all the knowledge you possess about agriculture, who have influenced most of that knowledge? ☐ My family ☐ My neighbours ☐ Researchers ☐ Government ☐ Internet

	☐ Self-learning ☐ Other (specify)
	3.30. As a farmer, where does most of your knowledge come from? ☐ From my family ☐ From my neighbours ☐ From the internet ☐ From trainings with government ☐ From trainings with researchers ☐ From my own experiments and observations ☐ Combination (Specify from whom) ☐ Other
Section 4 Changes in <i>Milpa</i>	4.1. What are some of the changes you have seen in the <i>milpa</i> system from when you start up to now?
	4.2. How have changes in <i>milpa</i> affected the way you use your knowledge/traditions to adapt to challenges? ☐ I don't use traditions anymore ☐ I use traditions only in specific circumstances ☐ I adapt traditions based on the problem/challenge ☐ I combine my traditions/knowledge with other type of knowledge ☐ I use traditions/knowledge the same way despite the problem/challenge ☐ Other (specify)
	4.3. How have changes in your <i>milpa</i> system affected the way you access to food and you and your family's diet?
	4.4. What would you consider are the major threats to small-scale agriculture? Choose all that apply

	☐ Changes in climate (Specify which one) ☐ Land and water issues ☐ Lack of support to farmers ☐ Lack of information on marketing ☐ Prices fluctuation (Unfair market prices) ☐ Plagues ☐ Framework and institutional limitations ☐ Environmental issues ☐ Lack of agricultural and rural development policies ☐ Poverty ☐ Expansion/Invasion of agro-business companies/monocultures ☐ Other (Specify)
Section 5 Climate Change	5.1. Why do you think the climate (el tiempo) is changing?
	5.2. Have you noticed any changes in the climate? ☐ Yes ☐ No
	5.3. If yes, how long ago did you start noticing changes in the climate (el tiempo)?
	5.4. During this time what are the changes you have seen in the weather? ☐ Drought ☐ More hurricanes ☐ Heavy Rainfall ☐ Temperature is higher ☐ Rainfall Fluctuation ☐ Fast decreasing of soil moisture (high evaporation) ☐ Other
	5.5. How does these changes have affected your farm? ☐ I have lost crops ☐ Soil is different

	☐ I get more pests ☐ Management is harder ☐ Crop Production has been reduced ☐ Other
	5.6. What changes have you done in your farm in response to weather change? ☐ Changing land preparation and planting times ☐ Using different crop varieties and crop types ☐ Implement soil conservation techniques ☐ Use more irrigation ☐ Searching for new water resources ☐ Improving irrigation system ☐ Increasing herbicides, fungicides, pesticides and fertilizers use ☐ Decreasing herbicides, fungicides, pesticides and fertilizers use ☐ Employ new crop rotation ☐ Fallow land ☐ Soil de-salination ☐ Reducing cultivation ☐ Other
	5.7. When did you start implementing these changes in your farm? ☐ 1 year ago ☐ 3 years ago ☐ 5 years ago ☐ 8 years ago ☐ 10 years ago ☐ More than 10 years ago
	5.8. Besides climate change, what are other challenges/things that have affected you as a farmer in general and that you have had to adapt in the past 10 years?
	5.9. When facing challenges like climate change or Covid, what are the aspects that you prioritize as a farmer?

	5.10. What are the aspects that you consider when deciding how to do your <i>milpa</i> every year?
	5.11. What is the basis for making these decisions? ☐ Experiences from the previous year ☐ Experiences/lessons learnt throughout the years ☐ Other people's experiences ☐ Government / academic institution recommendations ☐ Other (Specify)
	5.12. How do you get informed about the strategies/plans/support scheme in place for farmers to adapt to the impacts of climate change? ☐ Radio ☐ TV ☐ Internet ☐ Community meetings ☐ Neighbours/Family ☐ Meetings/Trainings from government representatives outside the community ☐ Collaboration with research institutions ☐ On-site visits from extensionists/researchers ☐ I don't get informed ☐ Other (specify)
Section 6 External Support	6.1. Are you currently part of any government support scheme? ☐ Yes (Which one?) ☐ No ☐ I prefer not to answer
	6.2. If you are currently receiving support from government what are some of the advantages and challenges of this support scheme?

	6.3. What do you think should be the priorities of agricultural support schemes when providing support to farmers?
	6.4. What is your perception in relation to all the technology and scientific knowledge available to improve agriculture and productivity?
	6.5. Do you think your ancestral knowledge and traditions should be considered by the government when working with you? ☐ Always ☐ Almost always ☐ Sometimes ☐ Almost never ☐ Never ☐ I don't care
	6.6. Do you think your ancestral knowledge and traditions are considered/valued/respected when working with: ☐ Agricultural Programs Always/Almost always/ Sometimes/ Almost Never/ Never ☐ Researchers/Universities Always/Almost always/ Sometimes/ Almost Never/ Never ☐ Collaborators Always/Almost always/ Sometimes/ Almost Never/ Never ☐ Social/Government Programs Always/Almost always/ Sometimes/ Almost Never/ Never
	6.7. What would be a good way for stakeholders to include your knowledge and traditions in their working strategies?
	6.8. What would be the best way to support you as a farmer in the face of a changing climate? Choose all that apply

	☐ Trainings (Specify what about) ☐ Support scheme/Incentives ☐ Fund for farmers ☐ Combining our traditional knowledge with scientific knowledge to develop working strategies/policies ☐ Promote exchange visits to learn from other farmers facing similar challenges (campesino-campesino method) ☐ Getting invited and contributing to climate change conversations and design of strategies ☐ Consider and respect our traditions and knowledge as farmers and within our local food systems ☐ Marketing opportunities/training ☐ Dissemination of information about climate change impacts and solutions/strategies and accessible in our language ☐ Reconstruction of local and fair economies ☐ Other (Specify)
	6.9. Have you ever been asked to participate in any trainings/discussions/forums related to climate change adaptations strategies? ☐ Yes, I have always attended ☐ Yes, but I have never attended ☐ Yes, but I have attended only sometimes ☐ No ☐ I don't know what that is
	6.10. If yes, what was the training/discussion about, and which role did you play?

Appendix 4. Semi-structured Interview (Spanish and English Version)



ENTREVISTA SEMI-ESTRUCTURADA

Comprender los microambientes y el potencial de los sistemas agrícolas tradicionales en un clima cambiante en México y Belice

Página de información

Estimado Participante,

Está invitado a participar en esta entrevista que examina el uso de conocimientos y estrategias de adaptación en el sistema de la *milpa*.

¿De qué se trata el proyecto?

La Universidad de Nottingham y Future Food Beacon están llevando a cabo este proyecto de investigación. El propósito de este estudio es desarrollar una comprensión profunda del uso y adaptación de los conocimientos (principalmente las costumbres y saberes antiguos) por parte de los agricultores en sus sistemas agrícolas (*milpas*) y en sus estrategias de adaptación ante el cambio en el clima y otras dificultades.

¿Quién está llevando a cabo el proyecto?

Este proyecto está siendo realizado por Karla G. Hernandez-Aguilar (estudiante de doctorado) y miembros de la Universidad de Nottingham (UoN)/ ECOSUR / UADY: Prof. Sarah Metcalfe, Dra. Franziska Schrodtt, Dra. Zinnia Gonzalez-Carranza, Dra. Birgit Schmook y Prof. Roger Medina .

¿Por qué lo invitamos a participar?

Se le ha invitado a participar en esta investigación porque es un agricultor maya que actualmente practica la *milpa*.

¿A que lo estamos invitando?

Se le invita a responder las siguientes preguntas lo mejor que pueda. Todas sus respuestas son confidenciales y la información recopilada en esta encuesta es anónima. La información se juntará con las respuestas de otros agricultores para su análisis y se utilizará solo con fines académicos.

¿Cuánto tiempo llevará su participación en esta encuesta?

La encuesta tomará de 60-90 minutos.

¿Existe algún riesgo asociado por participar en este proyecto?

El proyecto no tiene riesgos previsibles.

¿Cuáles son los beneficios potenciales del proyecto de investigación?

El conocimiento/información obtenido de este proyecto puede ayudar a otros investigadores, agricultores y partes interesadas involucradas en actividades agrícolas en el diseño de futuros

modelos y estrategias de investigación para apoyar a los pequeños agricultores frente a un clima cambiante.

¿Puede retirarse del proyecto?

La participación es voluntaria. Si acepta participar, puede retirarse del estudio en cualquier momento.

¿Qué pasará con su información?

La información y los datos recopilados del estudio se gestionarán y almacenarán en formato electrónico no identificable (anónimo) durante al menos 7 años y se mantendrán confidenciales en una base de datos segura. La información confidencial que proporcione solo será accesible para los investigadores a cargo de este proyecto. Los resultados se publicarán potencialmente en revistas científicas, así como en conferencias nacionales y / o internacionales, medios locales y reuniones comunitarias.

¿Con quién se puede comunicar si tiene preguntas, quejas o inquietudes sobre el proyecto?

El estudio ha sido aprobado por el Comité de Ética en la Investigación de la Escuela de Geografía de la Universidad de Nottingham. Si tiene preguntas o inquietudes asociadas con los aspectos prácticos de su participación en el proyecto o desea plantear una inquietud o queja sobre el proyecto, puede dirigirse a la Investigadora Principal Prof. Sarah Metcalfe por correo electrónico sarah.metcalfe@nottingham.ac.uk

Las quejas o inquietudes se tratarán de manera confidencial y se investigarán a fondo. Se le informará del resultado.

FORMULARIO DE CONSENTIMIENTO

Al marcar todas las casillas, da su consentimiento para participar en este estudio:

- ☐ He leído la página de información. Acepto participar en el proyecto de investigación titulado "Comprender los microambientes y el potencial de los sistemas agrícolas tradicionales en un clima cambiante en México y Belice" y las actividades descritas. Mi consentimiento se da libremente.
- ☐ El investigador y/o asistente de campo me ha explicado satisfactoriamente cuál es el propósito del proyecto y cómo me afecta, incluidos los riesgos potenciales. He tenido la oportunidad de hacer cualquier pregunta que pueda tener sobre el proyecto y mi participación. También se ha explicado que mi participación puede no tener ningún beneficio directo para mí.
- ☐ Entiendo que mi participación es anónima y que puedo retirarme en cualquier momento.
- ☐ Me han informado que los datos resultantes del proyecto pueden ser publicados en artículos de revistas o utilizados en presentaciones de conferencias o medios locales y comunitarios. No seré identificado (anonimato) en los materiales publicados.
- ☐ Entiendo que los datos de investigación recopilados en este proyecto pueden ser utilizados por los investigadores en futuros proyectos de investigación estrechamente relacionados con este proyecto. No se compartirá ni utilizará ninguna información que pueda identificarme (anonimato).
- ☐ Entiendo que mi información solo se divulgará de acuerdo con el consentimiento proporcionado.

Fecha



SEMI-STRUCTURED INTERVIEW

Understanding microenvironments and the potential of traditional farming systems in a changing climate in Mexico and Belize

Information Page

Dear Participant,

You are invited to take part in this interview which examines the use of knowledge and adaptation strategies in the *milpa* system.

What is the project about?

The University of Nottingham and the Future Food Beacon are conducting this research project. The purpose of this study is to develop an in-depth understanding of the use and adaptation of knowledge (primarily traditional ecological knowledge) by indigenous farmers in their agricultural systems (*milpas*) and in their adaptation strategies.

Who is undertaking the project?

This project is being conducted by Karla G. Hernandez-Aguilar (PhD Student) and UoN/ECOSUR/UADY members: Prof. Sarah Metcalfe, Dr. Franziska Schrodte, Dr. Zinnia Gonzalez-Carranza, Dr. Birgit Schmook and Prof. Roger Medina.

Why are you being invited to participate?

You have been invited to participate in this research because you are a small-scale Maya farmer currently practicing *milpa*.

What are you being invited to do?

You are invited to answer the following questions to the best of your knowledge. All your responses are confidential, and the information gathered in this survey is anonymous. Information will be collected with other respondents' responses for analysis and will be used only for academic purposes.

How much time will your involvement in the project take?

The interview will take from 60-90 minutes.

Are there any risks associated from participating in this project?

The project has no foreseeable risks.

What are the potential benefits of the research project?

The knowledge gained from this project may potentially assist other researchers and agricultural stakeholders in designing future research models and strategies to support small-scale farmers in the face of a changing climate. Upon completion of the survey a

voucher for agricultural supplies will be provided as a token of appreciation for the time invested in our study.

Can you withdraw from the project?

Participation is voluntary. If you agree to participate, you can withdraw from the study at any time.

What will happen to your information?

Information and data collected from the study will be managed and stored in non-identifiable (anonymous), electronic form for at least 7 years and remain confidential in a secure database. The information you provide will only be accessible to the researchers in charge of this project. The data will be potentially published in scientific journals as well as in national and/or international conference presentations. Individuals will NOT be identified by name in any publication/presentation. Your information will only be used as described above and it will only be disclosed according to the consent provided.

Whom do you contact if you have questions, complaints or concerns about the project?

The study has been approved by the School of Geography Research Ethics Committee at the University of Nottingham. If you have questions or concerns associated with the practical aspects of your participation in the project or wish to raise a concern or complaint about the project, you can approach the Principal Investigator Prof. Sarah Metcalfe by email sarah.metcalfe@nottingham.ac.uk. Complaints or concerns will be treated confidentially and fully investigated. You will be informed of the outcome.

CONSENT FORM

By checking all the boxes you consent to take part on this study:

- ☐ I have read the Information Page. I agree to take part in the research project entitled “Understanding microenvironments and the potential of traditional farming systems in a changing climate in Mexico and Belize” and activities outlined. My consent is given freely.
- ☐ I have been explained to my satisfaction by the researcher what the purpose of the project is and how it affects me, including the potential risks. I have had the opportunity to ask any questions I may have about the project and my participation. It has also been explained what the benefits of my involvement in this study are.
- ☐ I understand that my participation is anonymous and that I can withdraw at any time.
- ☐ I have been informed that the data resulting of the project may be published in journal articles or used in conference presentations. I will not be identified in published materials.
- ☐ I understand research data collected in this project may be used by the researchers in future research projects closely related to this project. No information that could identify me will be shared or used.
- ☐ I understand my information will only be disclosed according to the consent provided.

Date

Date:	Age:
Farmer ID:	Community:
TOPICS	QUESTIONS
<i>Milpa's</i> Definition	1. Could you please provide a definition of what a <i>milpa</i> is? // Podria por favor explicar que es la <i>milpa</i> ?
	2. What are other ways for you to call <i>milpa</i> ? // De qué otras formas le llama a la <i>milpa</i> ?
	3. What does the <i>milpa</i> represent to you? // Qué significado tiene para usted el hacer la <i>milpa</i> ?
	4. What are the reasons for you to do <i>milpa</i> ? // Cuáles son los motivos por los que hace la <i>milpa</i> ?
Priorities and Challenges	5. What are the things that you prioritize when doing <i>milpa</i> ? // Cuáles son las cosas que considera son más importantes al hacer la <i>milpa</i> ?
	6. What are the main challenges you face when doing <i>milpa</i> and as a farmer in general? // Cuáles son los mayores retos a los que se enfrenta al hacer la <i>milpa</i> y como agricultor en general?
	7. What would you consider are the major threats to small-scale agriculture? // Cuales considera son las cosas que amenazan/ponen en riesgo a los pequenos agricultores?
TEK and <i>Milpa</i>	8. How did you learn how to do <i>Milpa</i> ? // Cómo aprendió a hacer la <i>milpa</i> ?

	9. What are some of the traditions involved/practiced as part of the <i>milpa</i> ? // Cuáles son algunas de las tradiciones que se practican como parte de la <i>milpa</i> ?
	10. How did you learn these traditions? // Cómo aprendió estas tradiciones?
	11. Do you think traditions around <i>milpa</i> have changed? Can you give examples of how they have changed? // Cree que las tradiciones de la <i>milpa</i> han cambiado? Puede dar ejemplos sobre como han cambiado?
	12. How do you feel in terms of noticing that the traditions/knowledge around the <i>milpa</i> has changed or are not practiced anymore? // Cómo se siente al saber que esas tradiciones han cambiado o que ya no se hacen?
	13. Do you think it is important to preserve/rescue this traditions and knowledge? Could you explain why?// Cree qué es importante mantener/rescatar esas tradiciones? Porqué?
	14. Do you still practice these traditions? What has motivated you to keep practicing them or why do you stop using them? // Aún practica estas tradiciones? Qué lo ha motivado a seguir practicando esas tradiciones o porque dejó de usarlas?
TEK and Scientific Knowledge	15. Which techniques do you prefer/are more comfortable with when doing <i>milpa</i> ? Why? // Qué técnicas prefiere o con cuáles se siente más cómodo cuando hace la <i>milpa</i> ? ¿Por qué?
	16. What is your perception in terms of combining local traditions/knowledge with modern technology/scientific technology to improve your farming activities and productivity? // ¿Cuál es su percepción en términos de combinar tradiciones / conocimientos locales con tecnología moderna / tecnología científica para mejorar sus actividades agrícolas y su productividad?
	17. What do you think are the advantages and disadvantages of doing it? // Cuáles cree que son las ventajas o desventajas de hacerlo?

Changes in the Milpa	18. What are some of the changes you have seen in the <i>milpa</i> system from when you start doing agriculture up to now? // ¿Cuáles son algunos de los cambios que ha visto en el sistema de la <i>milpa</i> desde que comenzó a hacer agricultura hasta ahora?
	19. How have changes in the <i>milpa</i> system affected the way you use your traditions and/or other information (scientific knowledge) to adapt to challenges like climate change or Covid-19? // ¿Cómo han afectado los cambios en el sistema de la <i>milpa</i> la forma en que usa sus tradiciones y / u otra información (conocimiento científico) para adaptarse a desafíos como el cambio climático o Covid-19?
Climate Change and Unknown Challenges Adaptation Strategies	20. Why do you think the weather is changing? // ¿Por qué cree que está cambiando el clima?
	21. What are some of the impacts caused by climate change in your farm and livelihoods? // ¿Cuáles son algunos de los impactos causados por el cambio climático en su <i>milpa</i> y en sus medios de vida?
	22. What changes have you done in your farm in response to climate change impacts? // ¿Qué cambios ha realizado en su <i>milpa</i> para adaptarse (o en respuesta) a los impactos del cambio climático?
	23. What are some of the impacts caused by Covid-19 in your farm and livelihoods? // ¿Cuáles son algunos de los impactos causados por Covid-19 en su <i>milpa</i> y sus medios de vida?
	24. What changes have you done in your farming activities as a result of Covid-19? // ¿Qué cambios ha realizado en sus actividades agrícolas para adaptarse (o en respuesta) a los impactos del Covid-19?
	25. As a farmer, what are the things you pay the most attention to or are most important to consider (priorities) when facing/adapting to challenges such as climate change or Covid-19 pandemic? // Como agricultor, ¿cuáles son las

	cosas a las que presta más atención o las que son más importante considerar (prioridades) cuando se enfrenta o se adapta a situaciones como el cambio climático o la pandemia de Covid-19?
TEK and Adaptation Strategies	26. Besides climate change, what are other things that affect you as a farmer in general and that you have had to adapt? // Además del cambio climático, ¿en general, qué otras cosas le han afectado como agricultor y a las que se ha tenido que adaptar?
	27. How has your knowledge/traditions been impacted as a result of adapting to climate change and to different challenges? // ¿Cómo se han visto afectados su conocimientos / tradiciones como resultado de tener que adaptarse al cambio climático y a diferentes retos?
	28. How do you get informed about the strategies/plans/support scheme in place for farmers to face the impacts of climate change? // ¿Cómo se informa sobre las estrategias / planes / esquemas de apoyo disponibles para los agricultores para hacer frente a los impactos del cambio climático?
	29. What is your perception about the government support programs available for farmers/agriculture? And what is your level of involvement on these programs? // ¿Cuál es su percepción sobre los programas de apoyo del gobierno disponibles para agricultores ? ¿Y cuál es su nivel de participación en estos programas?
	30. What aspects do you think should be considered by agricultural stakeholders/partners when providing support to farmers to be more productive in the face of a changing climate? What should be the priorities? // ¿Qué aspectos cree que deberían ser considerados por las partes interesadas / socios agrícolas al brindar apoyo a los agricultores para que sean más productivos frente al cambio climático? ¿Cuáles deberían ser las prioridades?
	31. Do you think your ancestral knowledge and traditions are considered/valued by agricultural stakeholders when working with you? // ¿Cree que sus conocimientos y tradiciones ancestrales son considerados / valorados por las partes interesadas/socios agrícolas cuando trabajan con usted?

	32. Have you ever been asked/invited to participate in any trainings/discussions/forums related to climate change adaptations strategies? If yes what was your role? If not, do you think farmers should be part of this? Explain why // ¿Alguna vez le han pedido / invitado a participar en capacitaciones / discusiones / foros relacionados con las estrategias de adaptación al cambio climático? Si es así, ¿cuál fue su papel? Si no es así, ¿cree que los agricultores deberían ser parte de esto? Explicar por qué
TEK and Food Security	33. How have changes in the <i>milpa</i> affected the way you access to food and yours and your family's diet? // ¿Cómo han afectado los cambios en la <i>milpa</i> la forma en que accedes a los alimentos y la dieta tuya y familiar?
	34. Could you please describe what do you eat on a regular basis and where do these products come from? // ¿Podría describir qué come regularmente y de dónde provienen estos productos?
	35. Have changes in your traditions/use of local knowledge affected the way you access to food and your diet? // ¿Los cambios en sus tradiciones / uso del conocimiento local han afectado la forma en que accede a los alimentos y a su dieta?
Closing Questions	36. What are the main advantages of being a farmer? // ¿Cuáles son las principales ventajas de ser agricultor?
	37. What do you like the most about been a farmer? // ¿Qué es lo que más le gusta de ser agricultor?