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# A Community Capitals Assessment of Climate Adaptations to Traditional Milpa Farming Practices in Mayan Communities of Southern Belize

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**Abstract:** Climate change has exacerbated food and livelihood insecurity for Mayan milpa farmers in Central America. For centuries, milpa farming has been sustainable for subsistence; however, in the last 50 years, milpas have become less reliable due to accelerating climate change, resource degradation, declining markets, poverty, and other factors. Increasing climate-smart agriculture (CSA) practices may be needed. Using interviews with extension leaders and milpa farmers in Belize, this qualitative study examines the capacity for increasing CSA aspects of existing traditional milpa practices, specifically no-burn mulching, soil enrichment, and the use of cover plants. Applying a modified Community Capitals Framework, this study finds four key capitals were perceived by farmers and agriculture extension leaders as barriers for increasing CSA practices. Recommendations to reduce the key barriers include reinstating markets and crop-buying programs and easing border customs restrictions (Governance-Justice and Financial Capitals), improving roads and cellular access for farmers (Infrastructure Capital), and increasing budgets and resources for agriculture extension services and building farmer capacity for CSA practices of mulching, soil enrichment, and cover plants (Human-Capacity Capital). Reducing barriers to these key capitals can facilitate an increase in milpa CSA practices and crop productivity, promote food and livelihood security, and enable climate resilience of Mayan milpa communities in Belize.

**Keywords:** community capitals; climate-smart agriculture; resilience; milpa; Belize

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## 1. Introduction

The scale, speed, and scope of global climate change adversely and disproportionately impacts rural poor farmers—including Mayan milpa farmers in southern Belize—creating a higher risk for their food and livelihood insecurity [1–4]. A sustainable agriculture system for centuries, the milpa has become less reliable in the last 50 years due to accelerating climate change and increasing environmental degradation, population growth, declining markets, poverty, and other factors [4–14]. Increasing climate-smart agriculture (CSA) aspects of existing traditional milpa practices—specifically, no-burn mulching, soil nutrient enrichment, and cover plants—can promote a sustainable milpa agroecosystem [9,15]. CSA practices mimic or replicate the nutrient cycling in forest ecosystems while fostering sustainable crop production and climate resilience, among other benefits for milpas [2,3,9,15,16].

There are many studies examining impacts of CSA practices and climate resilience; however, more research is needed on how communities can use their own agency (i.e., strengths or assets) in addition to government interventions to build capacity for increasing CSA practices on milpa farms. Milpa farmers and district-level agricultural extension officers in the Department of Agriculture are interviewed. This study uses Community Capitals Framework (CCF) to examine data published in 2021 [17]; by using the asset-

oriented, multi-disciplinary lens, CCF can effectively identify barriers and conduits which influence milpa farmer capacity for adopting CSA practices [17–19].

By identifying barriers and conduits for increasing CSA practices, it may be possible to enable Government investments and interventions to target attention, resources, and action to promote climate-smart aspects of traditional milpa practices. The impact of government investment and intervention in CSA practices can help sustain increased crop productivity, enable food and livelihood security, and promote climate resilience of Mayan milpa communities in Belize [15].

## 2. Background and Literature Review

### *2.1. Food Security and Climate Change Vulnerability in Belize*

Food security depends upon reliable crop production while sustaining a healthy ecological balance in a farming system [20–24]. Sustainable crop production involves multiple factors, including economic, environmental, governance, cultural, and other factors [22,24]. Food security for milpa farmers in southern Belize depends on Government action such as increasing agriculture extension budgets and staff training, rebuilding local markets, improving infrastructure and disaster and risk management strategies, among other actions [15]. A lack of government action can negatively impact a community's food security, resilience, and ability to adapt to changing climates [20].

Belize is especially vulnerable to climate change with intensifying rains, storm intensity and frequency, longer dry seasons, more extreme temperatures, and rising sea levels [25]. Milpa farmers in Belize have perceived direct impacts of climate change, including drought, increased heat and sun exposure, offset rainy seasons, increased storm intensity, and an increase in pests and crop diseases [4]. Climate change accelerates soil erosion and land degradation which negatively impact crop reliability [15]. Climate and ecosystem changes in southern Belize have distinct impacts on the environment, crop production and economy, food security, public health, culture, and other factors in Belizean milpa communities [1,4,26,27].

Especially in combination with stressors of resource availability, population growth, and economic and government policy changes, climate change impacts have disproportionate adverse impacts on the rural poor who depend directly on natural resources for their food and livelihood security [2,3,15,28–32]. Further, climate change perpetuates a cycle of environmental degradation, poverty, and vulnerability in communities experiencing climate and ecosystem changes [33]. In Belize, there are important shortcomings in the current government management of climate change and disaster risk reduction response to effectively reduce impacts to climate vulnerable communities [15,27].

### *2.2. The Milpa Farming System and Climate-Smart Agriculture in Belize*

A milpa is a small-scale farming system of shifting cultivation traditionally involving slash-and-burn and/or slash-and-mulch techniques currently practiced in Mayan rural communities of Belize [8,9,34–36]. Milpa crop production is used for subsistence and selling at local markets [4,34]. Milpas provide most of a family's need for food, wood, and income [12,37]. Mulching and nutrient enrichment have been a part of the traditional milpa farming practice for centuries [36,38,39]. The milpa continues to be a significant aspect of Maya culture and tradition as Maya identity, ceremony, community, and livelihood are all rooted in the milpa [40,41]. The milpa system is not indefinitely resilient, however, "particularly with global economic and environmental change", including climate change [2], p. 75. Milpa food and agriculture system resilience encompasses a variety of economic, ecological, social, governance, and other factors; Government response is essential for milpa sustainability and food security [20].

Increasing climate-smart agriculture (CSA) practices can help sustain the traditional milpa system, increase crop production, support food security, and build resilience to a changing climate [28,42–44] while maintaining the health of ecosystems in Belize [42]. The

aim of CSA is to "increase productivity in an environmentally and socially sustainable way, to strengthen farmers' resilience to climate change, and to reduce agriculture's contribution to climate change" [3], p. 14.

CSA aspects of traditional milpa practices in southern Belize include the use of mulching, nutrient enrichment, plant cover, forest and resource conservation, and erosion management [9,15]. Mulching involves slashing (clearing) forests to use nutrient-rich "black" soil; mulching does not use burning but rather allows debris to decay on site [15]. Mulching improves soil's water holding capacity, organic matter, fertility, and stability, as well as reducing runoff and weed population and growth [2,39,43–45]. Mulching also regulates surface temperatures (improving moisture and germination), restores degraded soils, allows for shorter fallow periods, reduces need for fertilizers, and stabilizes crop yields [35,36,46–49].

Soil nutrient enrichment inputs improve soil conditions for production [35,36,46]. Soil enrichment can include adding chemical or nonchemical fertilizers and integrating effective microorganisms (EM) into the soil to break down slashed debris faster and build soil fertility [9,28]. EM involves adding organic soil amendments; these provide stability in crop production and "may increase yield by up to 15% in tropical conditions" [50]. Plant-cover allows for less heat and sun exposure to protect soil. Increasing CSA technologies such as these in the milpa farming system can facilitate increased crop production and better food and livelihoods security for milpa farming communities in Belize [15,29,45,51].

### *2.3. Government Agricultural Extension in Belize*

CSA practices and sustainable crop production depend upon government policies for climate adaptation and response at the local level [3,4,52]. The term 'government' refers to the national Government of Belize (GoB) and the Agricultural Extension services under the Department of Agriculture, a division of the Ministry of Agriculture, Fisheries, Forestry, Environment, Sustainable Development and Immigration (MAFFESDI) [4]. Government agricultural extension provides information and demonstrations to farmers for site-specific CSA technologies and practices [2,9,52–54]. In Belize, district extension offices are effective to promote CSA in milpa communities because they work locally with farmers as partners and within the cultural traditions of the farmers [4,9,15].

The GoB vision for agriculture development includes "climate change adaptation, environmentally sound production practices, conservation of natural resources, and risk management mechanisms" [52], p. 12. A national report on knowledges, attitudes, and practices of famers in Belize states the need for government action to "better protect the health of the farming community, consumers, and the environment" [55], p. 7. The GoB can promote "more resilient farming systems and practices (e.g., climate-smart practices), as well as sound coordination, exchange of information, methodologies, and tools between experts and institutions" [26], para. 12].

There are multiple operational and budgetary barriers for extension including a lack of resources, staff, and technical training in CSA technologies [52]. Moreover, in the rural Toledo District of southern Belize, there are only four extension officers who are responsible for serving a large district of 52 communities [4]. Extension officers in Belize have stated a sense of powerlessness due to these operational, staff, and budget barriers; as such, extension is less effective to facilitate climate resilient strategies in milpa communities [6,15,26,56,57].

### *2.4. Research Framework: Community Capitals in the Milpa Socio-Ecological System*

This study uses a Community Capitals Framework (CCF) to assess the barriers and conduits of CSA practices in milpa communities. CCF is a strengths-based, asset-driven framework which considers multiple and transdisciplinary factors. CCF is useful for examination and problem-solving for complex system issues such as food security and climate change adaptation [3,4,9,17,18,58,59].

There are seven original Community Capitals developed by Flora and Flora, including: Natural, Cultural, Human, Social, Political, Financial, and Built (Infrastructure) Capitals [17]. CCF was modified for this study to include: (a) Human-Capacity, (b) Social, (c) Natural, (d) Infrastructure, (e) Governance-Justice, (f) Financial, and (g) Cultural Capitals. CCF identifies systems linkages, patterns, and relationships between several multi-perspectival factors [18,19]; further, it identifies community strengths and recognizes "each community possesses resources, in spite of the conditions of poverty or marginalization, which can be used as the foundation of their resilience" [17].

Each Community Capital can influence the larger milpa socio-ecological system (SES); the milpa SES is a linked network where an impact to one part of the system—the loss or degradation of soil due to storm erosion, for example—can affect the human system, such as food security and farmer livelihoods [12,58,60]. Reducing barriers (i.e., to one or more capitals) can positively influence the whole milpa system [17,18] and demonstrate how climate adaptive practices can advance an entire system further [61–65].

Each capital (individually) has direct, indirect, overlapping, and rebounding impacts with other Capitals. The capitals (collectively) are intrinsically linked where a strong set of capitals can create the conditions for community resilience. Examining capitals in the milpa SES context integrates sustainable livelihoods, culture, human well-being, and livelihoods of the community [65–68]. Individually and collectively, the capitals can foster capacity-building, sustainable agriculture, and climate resilience [18]. "When all the capitals are working together—and when you don't ignore any of them—(a community) is more likely to have positive outcomes, such as heathy ecosystems, economic security for all, and social inclusion" (C. Flora, personal communication, 15 November 2018).

## 3. Methods

This qualitative study uses phenomenology and semi-structured interviews to elicit and analyze common lived experiences on milpa farming practices and climate-smart agriculture (CSA) modifications. Qualitative data were collected from interviews with five milpa farmers and three extension leaders in Belize. Data analysis was inductive and comparative; the findings are presented in themes and categories in the Results section [69].

### *3.1. Research Design and Study Setting*

Phenomenology was used to find the emergence of common themes and patterns in common phenomena [15,70,71]. Phenomenology is useful to investigate factors involved with a farmer's decisions to adapt to more sustainable practices [72] and helps to "develop an understanding of complex issues that may not be immediately implicit" in participant responses [71, p. 301]. Using semi-structured interviews allowed for participants to use their own words, descriptions, and stories [70,73,74]. The study was conducted in and near milpa farming communities in the Toledo District, the southernmost district in Belize. The district's population is nearly 50% Q'eqchi' (Kekchi) Maya, 20% Mestizo, and 17% Mopan Maya [75]. This qualitative study seeks to more deeply understand how milpa farmers make decisions to adapt their traditional practices to changing climatic and other conditions.

### *3.2. Sampling and Data Collection*

Participants interviewed for this study included five milpa farmers from Pueblo Viejo and Indian Creek villages as well as three government agriculture extension leaders from the Toledo District who work directly with milpa farmers. First, the villages were visited to interview community farmers. The milpa farmers who participated in the study were interviewed at their village households in rural Toledo District; semi-structured interviews were conducted in or just outside the participants' homes which revealed insights into the farming practices being used. A village translator was used during the interviews. The subpopulation of 'head milpa farmer' for each household was purposive as it was

critical to elicit farmer perspectives as they have the most direct knowledge of changing conditions and practices of the agriculture system. Three extension officers (of four total for the district) were interviewed at their district office near the town of Punta Gorda.

All eight participants in this study were male, ranging from 25 to 64 years of age. Farmer households were selected in both villages using stratified random sampling. A printed data sheet of face-to-face semi-structured interview questions and small audio recorder were used to record farmer and extension staff responses. All interviews followed a voluntary and informed consent procedure.

The survey used for milpa farmers included demographic and farming practice questions as well as the best means for attaining important real-time information. Specific question included: "In what ways are your farming methods sustainable/unsustainable? Will your children/grandchildren be able to farm the same way as you? Explain," and "Do you have the information, equipment, and access you need to farm sustainably? Describe. If not, why not? What information could you use the most," and "Where do you get help and information/Where would you contact if you had a farming problem?".

The survey used for extension officers included questions about themselves and their work in milpa communities, including: "Describe any barrier (s) (i.e., roads/works, work time needed) or conduits (s) (i.e., collaboration/sharing) for sustainable agriculture practices in your district," and "Do you work with milpa farmers," and "How often do you do extension in milpa communities? How is it requested/responded to," and "What is/are the most needed intervention (s) for sustainable agriculture or agroforestry in milpa communities?".

### *3.3. Data Analysis and Synthesis*

The data analysis and synthesis processes included three coding phases as described in Strauss and Corbin [76], Stuckey [77], and Creswell [70], including: 1. open or analytical coding, 2. Axial (reduction) and clustering coding into themes, and 3. selective coding, or integration of codes into dominant thematic categories [71,76–81]. Open coding was conducted upon the first review of the interview transcript where responses were sorted into larger categories. Both a priori (i.e., Community Capitals categories) and a posteriori coding was used in this process. Axial coding was then conducted on a second review of interview transcripts, where themes and subthemes were clustered into meaningful units.

After open and axial coding was complete, major thematic categories were determined by a selective coding process which included crystallizing the code units into dominant themes [70–72,81]. Selective coding also helped to find conceptual linkages, patterns, and relationships among the major thematic categories [76–81]. The identification of barriers and conduits for increasing CSA practices occurred during the crystallization process. Especially useful for this complex study, the process of crystallization used multiple perspectives to blend data to produce thick description and knowledge of a phenomenon as well as a deepened, inclusive, and multi-perspectival interpretation of it [15,79–81].

## 4. Results

This study analyzed the perceived barriers and conduits for seven Community Capitals and their influences on CSA practices in milpa communities. The seven capitals used were: Human-Capacity, Social, Natural, Infrastructure, Governance-Justice, Financial, and Cultural Capitals. Common responses among all participants interviewed for this study are summarized and presented in Table 1 for each capital. Each capital category specifically assessed the capacity for farmers to increase CSA practices; barriers and conduits for increasing CSA practices were determined for each capital category.

The study finds three Capitals—Social, Natural, and Cultural Capitals—are perceived as overall conduits for increasing CSA practices; the other Capitals—Human-Capacity, Infrastructure, Governance-Justice, and Financial Capitals—were perceived as overall barriers. For the purposes of this study, the four barrier Capitals are examined, with notable individual responses presented as excerpts in the Results Sections 4.1–4.4.

**Table 1.** Summary of results. A Community Capitals assessment of barriers and conduits which influence the increase of CSA practices of no-burn mulching, soil enrichment, and plant cover in milpa communities in southern Belize.

| Community Capital | Description | Perceived Barriers to (Factors against) Increasing CSA Practices (−) | Perceived Conduits (Factors for) Increasing CSA Practice (+) | Overall CSA Influence |
|---|---|---|---|---|
| Human Capacity Capital | Knowledge, skills, abilities, expertise, creativity, technology, innovation; health, well-being, security, capacity-building, capability to adopt innovations | More visits/information and training, and monetary resources are needed from extension on pesticide management and CSA (non-burn) innovations of mulching, soil enrichment and cover plants (−)CSA no-burn practice increases occurrence of snakes (−) | Some CSA information and solutions: mulching, cover plants, pesticide dosages – transferred from extension to community, few and far between (+). Adaptive technology and innovations from one extension officer: Effective microorganisms (EF), integrated pest management (IPM), nitrogen-fixing cover plants such as mucuna and arachis (+) | Barrier. More CSA information, training, and capacity-building (−) needed including: Soil enrichment; fertilizer/pesticide application; resource management; economic development; CSA technologies (mulch-only, EM, IPM, and nitrogen-fixing cover plants (−). More information and strategies needed for snake management (−) |
| Social Capital | Relationships, connections, participation, communications, stewardship | More CSA information and innovations are needed from extension so farmers can respond to uncertain climate/seasonal variability (i.e., temps and rainfall (−) | Extension works directly with farmers to transfer CSA information and demonstrate innovations & solutions (+).Farmers share innovations and solutions within community (+), stewardship for natural resources [soil, streams, forests] (+) | Conduit. Established relationships and trust for innovation transfer, social support for CSA practices (+). Solutions shared and diffused to community members (+) |
| Natural Capital | Environment, ecosystem services, geography, air, soil, water, forests, rivers, geomorphology, insect pests | CSA practices don't address forest clearing (−); cleared forest ("black") soil is nutrient-rich to rotate crops (−) but use less fertilizer (+); alternative is nutrient depleted soil (−).Exclusive burn-only practices lose soil nutrients (−). Nutrient-depleted soil needs fertilizer inputs (usually chemical) (−). More pests/crop disease need more inputs (−) | Mulching =>more decomposition/nutrient enrichment (+), shorter fallow times (+) =>more crop production (+). Soil enrichment (non-chem.) and cover plants => protect soil from nutrient loss (+) and erosion (+); regulates soil moisture (+) and temperature for fertility/germination (+); better water management (+). Non-burning => better air quality, wildlife, forests, rivers/creeks (+) | Conduit. (No-burn CSA milpa practices). Better soil protection (sun exposure, moisture loss, erosion); nutrient enrichment; better air quality, and overall, less chemical inputs (+) CSA aspects of milpa farming facilitate more reliable, sustainable, increased crop production (+). More government information and action needed for pest management, chemical inputs, fire, and forest clearing impacts (−) |
| Infrastructure Capital | Infrastructure, telecommunications, housing, roads, | Lack of reliable infrastructure; limited Belize cellular service (−) poorly | Markets and cellular service from Guatemala are good (+), but | Barrier. Lack of reliable infrastructure and access to markets (−); |

| | | | | |
|---|---|---|---|---|
| | electricity, water, utilities | maintained roads (−), and unreliable water and electricity (−). Bad roads limit farmer access to farms, communities, and markets (−) => limits income, more insecurity (−) | border/immigration policies create a challenge (−) | limited cellular service (−), unreliable water and electricity (−); bad roads (−); limits to farmer access to farms, communities, and markets => impacts livelihood security |
| Governance-Justice Capital | Leadership, government, power and influence, civic engagement, accountability; rights, access, marginalization under-representation, exclusion, social justice, and border/immigration | Historical marginalization and distrust of Government (−); discontinued local markets (−) and crop buying programs (−). Border restrictions reduce access to markets in Guatemala (−); Lack of information shared on safe pesticide use (−); Lack of reliable infrastructure (−). Extension barriers: a) operational constraints with a lack of budget, staff, training; (b) efficacy in milpa communities: high poverty | Extension works within milpa traditions (+) to show CSA adaptations and technologies (+); shares other farmer successes in mulching, effective microorganisms, nitrogen-fixing cover plants (used by Amish/Mennonites), and integrated pest management (+) | Barrier.<br>Farmers need more extension information, resources, and financial support for CSA practices (−). Extension barriers: Lack of budget, staff, resources, and training in CSA (−) and lack of pesticides information [type, amount, safe application] (−). Lack of government addressing rural poverty, unreliable infrastructure, lack of markets, lack of quality land to farm (−). Lack of government action to ensure stated priority of sustainable agriculture and community resilience to climate change impacts (−) |
| Financial Capital | Monetary resources, workforce, business, industry, enterprise, markets, economic development, investments, poverty, Scarcity | More insect pests = less production/income (−) and higher pesticides expenses for famers (−). Farmer poverty (−), lack of government assistance and land (−) => higher vulnerability (−). Government barriers to markets: Discontinued markets, no government purchase of crops, lack of local markets; low markets/prices (−)<br>Low operational budget for extension (−), lack of vehicles, fuel, staff (−), lack of CSA training (−) | Fertilizer technology can stabilize and increase crop production (+), security for subsistence (+), and livelihoods (income from local markets) (+). Non-chemical enrichment/cover plants = low/no cost (+) | Barrier. CSA practices promote sustainable crop production and income (+). Lack of (or discontinued) markets (−); no government crop-buying program (−), market access barriers (−). More pest => increased farmer expenses for fertilizer and pesticides (−), unless non-chem technology and financial support transferred. Extension efficacy barriers due to lack of operational budget (−) |

| | | | | |
|---|---|---|---|---|
| Cultural Capital | History, heritage, values, customs, traditions, identity, sense of community | Adaptation (and capacity to adapt) for new CSA technologies and practices is slow-moving, [except with youth] (−) => a higher # of older traditional farmers (−). More elderly/fewer youth milpa farmers (−) | Extension works within Maya cultural traditions of milpa farmers to find sustainable solutions (+)<br>Modifying traditional milpa practice for CSA-only (mulching, ground cover, soil enrichment, erosion control) can improve capacity and longevity (sustainability) for milpa farming traditions (+) vs. burn-only milpa degrades soil | Conduit. Extension can work within Maya cultural traditions to promote CSA aspects of traditional milpa practice (no burn, mulching, ground cover, soil enrichment) especially among youth farmers; this can improve sustainability of crop production and cultural traditions of milpa farming system (+). CSA modifications to traditional milpa practices can promote sustainable production (+) => more food and livelihood security (+) => better community resilience (+) |

### *4.1. Human-Capacity Capital*

Human-Capacity Capital includes community assets such as knowledge, skills, abilities, health, security, and capacity to innovate. From interviews, participants perceived more barriers than conduits regarding Human-Capacity Capital's influence for CSA practices in milpa communities. Specifically, Government of Belize and agricultural extension service barriers include: (a) The need of milpa farmers for information and demonstration of successful climate-smart agriculture (CSA) technologies to increase sustainability and crop production and (b) milpa farmers' need for more support for building capacity for low or no-cost soil enrichment and soil protection innovations.

A government extension officer stated his goal was not to challenge traditional milpa methods, but try to promote a few effective CSA modifications (i.e., soil conservation, irrigation systems, and integrated pest management). Another government extension officer said they need to "demonstrate [to the farmer] a way to adequately compensate for what they are moving … we need to look at injecting proportionate technology in the milpa system, and then look at how the farmers react to that injection". Government extension officers described low or no-cost CSA technologies that can help milpa farmers sustain and increase crop production, including the use of mulch-only, nitrogen-fixing cover plants such as arachis, and soil enrichment techniques such as chicken manure, mucuna beans, and effective microorganisms or 'EM', and integrated pest management.

Government extension officers stated about half the milpa farmers in the Toledo district practice mulching. Government extension officers explained there are multiple benefits to mulch-only—or leaving debris to rot; no-burn milpa practices are better for air quality, for using less chemical inputs, and for soil temperature, moisture, fertility, and erosion. Also, one government extension officer explained mulching allows "[the grass to] covers the soil [and] …there's a little moisture by the roots of the plant [and] it will keep the soil cool instead of in the hot sun …so it does work. It does work". And, if milpa farmers burn-only (with no mulching), "…[and] then you have a long drought, how do you keep moisture? And, those are the things that we have to make farmers aware of—it's a chain of reaction". One farmer stated he prefers mulching versus burning: "Just leave

[debris] there, and it'll get rotten…because the stump, it holds a lot of soil; when it's raining, it won't flush off. So, just leave the stump right there in till it gets rotten".

Milpa farmers stated they prefer rotating crops on nutrient-rich "black" soil to avoid using (and paying for) fertilizers for the nutrient-depleted farmed soil over time; "Black soil is better [to farm]" and that "works for us". Another farmer explained if he does not plant on black soil, it gets too dry and hard, "but, if we change every year, it doesn't need fertilizer". A third farmer stated if government supported them with soil enrichment information and assistance, he could avoid the need to "chop" forest to use the black soil.

One government extension officer explained many farmers are using soil enrichment techniques: "A lot of farmers, they are starting to use organic material—like, chicken manure. They are using a lot of EM (effective microorganisms) agriculture to build up the soil fertility". There are also other forms of nutrient enrichment: "We introduce some types of fertilizer that you incorporate in the soil…[for example] mucuna beans: the Mennonites [the less mechanized Amish community] use it a lot, you know; they don't use a lot of synthetic fertilizer, they only use these types of mucuna beans".

A farmer expressed interest in soil enrichment through intercropping and EM: "It would be interesting to bring something with the soil and mix it up—and put plants there like tomatoes. You could plant when you mix up the soil… the [plants] come very good. And, with corn too". One government extension officer promoted arachis (Arachis glabrata), a wild peanut perennial. He explained arachis is useful for milpa farmers as an effective ground and soil cover and as a nitrogen-fixing plant. Government extension officers explained CSA practices mimic or replicate the nutrient cycling in forest ecosystems while allowing for sustainable production of agriculture.

Participants interviewed perceived improvements to soil enrichment and other CSA practices can positively influence production. However, Human-Capacity Capital barriers (i.e., needing more information and demonstration on CSA technologies, capacity-building, pest management) were perceived to be primarily barriers, exacerbating perceived exclusion and marginalization and negatively influencing food and livelihood insecurity. These Human-Capacity Capital barriers have direct linkages to Governance-Justice, Natural, and Financial Capitals, as well as indirect linkages to other Capitals.

### *4.2. Infrastructure Capital*

Infrastructure Capital includes built community assets such as housing, roads, telecommunications, electricity, water, and utilities. Shortcomings in infrastructure can exacerbate a milpa farmer's sense of marginalization and be a barrier for government assistance and climate resilience. From interviews, participants perceived more barriers than conduits regarding Infrastructure Capital's influence for CSA practices in milpa communities. Specifically, these barriers include: (a) A lack of reliable basic services, such as water and electricity; (b) bad or poorly maintained roads, and (c) limited Belizean cellular service. Unreliable water and electricity services have been a barrier for milpa communities. One farmer stated there is no government assistance to fix a failing water system or getting electricity for the village to address vulnerability of solar electric outages during inclement weather.

Milpa farmers and government extension officers identified "bad roads" and the lack of Belizean cellular service in rural areas of southern Belize to be barriers for farming. Bad road conditions limit access to and from communities and farms and reduces farmer access to markets. The limitation of access negatively impacts farmer access, income, and livelihood security. Limited cellular service is also a barrier. In Pueblo Viejo village, farmers use TIGO service (a Guatemalan phone service) due to non-existent or unreliable Smart or Digicel service in Belize. Milpa farmers stated that phone calls are the best way to reach them with extension information or to alert them to a community meeting or demonstration. One farmer stated he does not have other technology other than his cell phone and "it doesn't have signal".

Participants interviewed perceived improvements to infrastructure can positively influence CSA farming practices; however, Infrastructure Capital barriers such as unreliable electricity and water services, poor roads, and poor cell service were perceived as barriers for CSA practices as they exacerbated the impacts of marginalization, food insecurity, and poverty; further, these barriers reduce capacity for income and add hardship and expense to farmers. Infrastructure Capital barriers have direct linkages to Governance-Justice and Financial Capitals, as well as indirect linkages to other Capitals.

### *4.3. Governance-Justice Capital*

Governance-Justice Capital includes community assets such as leadership, local and national governments, rights, access, marginalization, social justice, and immigration. From interviews, participants perceived more barriers than conduits regarding Governance-Justice Capital's influence for CSA practices in milpa communities. Specifically, these barriers include Government of Belize and agricultural extension services gaps such as: (a) Historic marginalization, exclusion from the Government of Belize (GoB), and persistent poverty of the Maya in Toledo District; (b) government closure of markets and crop purchase programs and a lack of government assistance to build or open back access to markets; (c) persistent need for information and support from the Government extension officers, especially for pest management including correct types, quantities, and safe applications for fertilizers and/or pesticides; and (d) a lack of government support for extension services as a barrier to facilitate CSA practices for milpa farmers.

There is perceived historical marginalization and exclusion in milpa communities. There has been a lack of quality land access for milpa farmers. Farmers identified being excluded as only people in power get the good land, and "the farmers are staying without land, or they're leaving them the worst land".

Milpa farmers have also experienced a discontinuation of local markets and new government border and immigration policies which limit their access to Guatemalan markets. Lack of or closure of markets is a barrier for milpa communities. A government extension officer explained there is no indication for government assistance for bringing back markets to sell milpa crops; further, "market prices are not stable; at some point we have a crop (that is) very cheap (due to market abundance)". The Belizean market price for milpa crops combined with close proximity and high demand for their crops in Guatemalan markets has made it easy to sell in Guatemala; however, the Government of Belize (GoB) set up new customs and immigration services at the border which make it more difficult for farmers to continue to sell their crops there.

Government extension officers perceived the lack of staff training and inadequate operational budget for extension as barriers to farmers increasing CSA practices. Government extension officers perceived barriers including a lack of district budgets, limited staff and resources (e.g., vehicles, fuel), and a lack of training in CSA technologies and innovations. One farmer expressed his frustration: "I just try to help myself because (I) can't find (any help from government)". Another farmer stated: "We were told that agriculture department is there, but, yet, all this information is hidden. It's unknown; sometimes they pass on the information, and sometimes they doesn't [sic] (inferring political bias)".

Milpa farmers perceived a lack of information and service from government extension officers. One farmer stated that any help from extension is scarce: "I believe the government doesn't have money to finance that type of service… Well, I have the suspicion that all the information, they know about it. They know ... but these guys don't have financing...there's a lot of excuses...they don't have money or they don't care…".

There is also a perceived lack of information on pest management and safe pesticides application (i.e., type, amount, safe application techniques). Farmers interviewed primarily get their chemical information (i.e., dosages) from the supplier or store. A Pesticides Control Board Extension leader said farmers relying on chemical information from the stores is common, but also biased (i.e., toward selling more chemical quantity than needed). A farmer said: "For each crop, if you go buy fertilizer for different types of crops,

there is a different grade of fertilizer. For corn, it's a different amount of nitrogen, phosphorus, and potassium—and for fruit trees, it's a different combination of nutrients… So, I have to know that (or) I (have to) rely on the person selling".

Participants interviewed perceived improvements in government action can positively influence CSA practices. However, there are Governance-Justice Capital barriers including a lack of trust to improve historic marginalization and poverty conditions, a closure of border immigration creating a barrier to local markets; district budget deficiencies for extension operations (to transfer CSA technologies and serve milpa communities), and a lack of information sharing on safe pesticide application. extension support should be prioritized to ensure the GoB's stated priority of sustainable agriculture and community resilience to climate change. Participants in this study perceived Governance-Justice barriers to exacerbate food insecurity, poverty, and marginalization of milpa farmers. Governance-Justice Capital barriers have direct linkages to Human-Capacity, Cultural, Infrastructure, and Financial Capitals, as well as indirect linkages to other Capitals.

### *4.4. Financial Capital*

Financial Capital includes community assets such as monetary resources, workforce, business, industry, enterprise, markets, economic development, investments, poverty, and scarcity. From interviews, participants perceived more barriers than conduits regarding Financial Capital's influence for CSA practices in milpa communities. Specifically, these barriers include: (a) milpa farmers' lack of income due to discontinued local markets and no government crop-buying program; (b) limited market access from bad roads and border restrictions; and (c) higher expenses and no government assistance for fertilization inputs and crop pest and disease management.

The lack of markets for milpa farmers has a direct impact on poverty, farmer livelihood and food security. Market problems in this area stem from unstable or fluctuating prices (i.e., corn sells too cheap due to market abundance). One government extension officer stated the market barriers are very difficult on farmers: "Sometimes the market prices are not stable; at some point we have a crop (that is) very cheap; so, there is abundance. So… there is excess production at some points of the year". In addition to a lack of markets, the GoB no longer buys crops from milpa farmers for export; in what used to be a strong domestic market where the government bought corn, beans, and rice right from the village, "Right now you can't. The government no want that [sic]. Fifteen years ago, the government buy all—everything what you got …corn, beans, rice—right here. They stop—I don't know (why). They say they can't find a market again for export".

Participants interviewed perceived improvements in markets can positively influence CSA practices. However, there are barriers such as a lack or closure of markets impacting income ability, a closure of government crop-buying program, and lack of government financial assistance for farmers. Participants in this study perceived Financial Capital barriers exacerbate food insecurity, poverty, and marginalization of milpa farmers. Financial Capital barriers have direct linkages to Human-Capacity, Governance-Justice, and Infrastructure Capitals, as well as indirect linkages to other Capitals.

## 5. Discussion

Four key Community Capitals—Human-Capacity, Infrastructure, Governance-Justice, and Financial Capitals were perceived by participants in this study as primarily barriers to increasing climate-smart agriculture (CSA) practices in milpa communities.

(1) Human-Capacity Capital barriers were perceived to include a lack of information and technology transfer from government extension on CSA technologies (i.e., effective microorganisms), capacity-building for community-based solutions, and effective pest management;

(2) Infrastructure Capital barriers were perceived to include a lack of government improvements to unreliable electricity and water services, poor roads (inhibiting access to

farms and markets), and poor cell service coverage (limiting information transfer and notifications);

(3) Governance-Justice Capital barriers were perceived to include a lack of trust to improve historic marginalization and poverty conditions, a closure of border immigration creating a barrier to market access; district budget deficiencies for government extension services, and a lack of information sharing on safe pesticide application; and

(4) Financial Capital barriers were perceived to include a lack of—or closure of—markets impacting income ability, a closure of government crop-buying programs, and lack of government financial assistance for extension and farmers.

After synthesizing the data in four thematic categories, common impacts and a key linkage between the Community Capital categories emerged. Common impacts across the four barrier capitals were perceived as: (a) a lack of extension services; (b) a lack of market access and income potential, (c) poor infrastructure, and (d) a sense of continued marginalization for milpa farmers. Many of these impacts are consistent with previous studies on barriers to the adoption of CSA practices by milpa farmers, including farmers' attitudes to risk, low market prices, expenses for farm inputs, and access to extension services [28,82] A key linkage among all capital barriers is 'government', specifically, the inability and/or unwillingness of the GoB (including government agricultural extension) to facilitate meaningful interventions to increase CSA practices.

Limitations of this study include its small sample size and short temporal and spatial scale. Small-scale qualitative studies can effectively examine behaviors, impacts, and resilience of components of the socio-ecological system (SES). However, more development of multi-scalar transdisciplinary research and theory is needed to discover patterns and longer-term impacts of socio-ecological processes [83]. Additionally, more qualitive research on CSA conduits and barriers is needed to understand how various capitals function within their SES and how those capitals impact community resilience to system changes such as climate change, resource degradation, and so on.

## 6. Conclusions

Climate change has exacerbated food and livelihood insecurity for Mayan milpa farmers in Central America. For centuries, milpa farming has been sustainable for subsistence; however, milpas have become less reliable due to accelerating climate change and other changing conditions. Increasing climate-smart agriculture (CSA) practices is needed. Unfortunately, the capacity for increasing CSA aspects of existing traditional milpa practices—specifically, no-burn mulching, soil enrichment, and the use of cover plants—is hindered by several barriers.

Four Community Capitals barriers were perceived by milpa farmers and agriculture extension leaders as barriers to increasing CSA practices. These barriers include the need to reinstate markets and crop-buying programs (Human-Capacity Capital), increasing government budgets and resources for Toledo District extension services (Financial Capital), and infrastructure improvements to roads, cell coverage, water, and electricity service (Governance-Justice and Infrastructure Capitals). A key factor among these impacts included the term 'government', specifically, the inability and/or unwillingness of the Belize government (including government agricultural extension) to facilitate meaningful interventions to increase CSA practices.

It is important to identify the capitals barriers which need attention, resources, and government action. Each of the capitals (individually) has direct, indirect, overlapping, and rebounding impacts with other capitals. The capitals (collectively) are intrinsically linked where a strong set of capitals can create the conditions for community resilience. Effective government action to reduce or remove barriers in the four key Community Capitals can positively influence CSA practices in the larger milpa socio-ecological system. The Government of Belize can help reduce capital barriers identified in this study and thus facilitate an increase in milpa crop productivity, help sustain milpa farming

traditions, promote food and livelihood security, and enable climate resilience of Mayan milpa communities in Belize.

## 7. Recommendations

Based on interviews from milpa farmers and extension leaders, there are perceived barriers against increasing climate-smart agriculture practices in milpa farming communities. It is recommended for the Government of Belize Ministry of Agriculture, Fisheries, Forestry, Environment, Sustainable Development and Immigration (MAFFESDI) to focus interventions on specific Human Capital, Financial, and Governance-Justice capital barriers. Government of Belize and agriculture extension services can facilitate an increase of CSA practices in milpa communities in Belize in the following ways:

(1) Human-Capacity Capital recommendations to build farmer knowledge and capacity for CSA practices: Increase budgets and resources for extension services to support CSA technical training and transportation resources and facilitate a wider reach for pest management and CSA technologies of mulch-only, nutrient enrichment, and cover plants.

(2) Financial, Infrastructure, and Governance-Justice Capitals recommendations for easing economic stress on farmers: Reinstate markets and crop-buying programs; improve roads and cellular access for farmers; increase government financial assistance for farmers; and ease border customs restrictions to increase farmer access to markets in Guatemala.

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