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Climate-Smart Adaptations and Government Extension Partnerships for Sustainable Milpa Farming Systems in Mayan Communities of Southern Belize

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Abstract: There are disproportionate adverse impacts related to climate change on rural subsistence farmers in southern Belize, Central America who depend directly on natural resources for their food and livelihood security. Promoting a more resilient farming system with key climate-smart agriculture (CSA) adaptations can improve productivity, sustainability, and food security for Mayan milpa farming communities. Once a sustainable system, the milpa has become less reliable in the last half century due to hydroclimatic changes (i.e., droughts, flooding, hurricanes), forest loss, soil degradation, and other factors. Using interviews with both milpa farmers and Extension officers in southern Belize. This qualitative study finds several socio-ecological system linkages of environmental, economic, socio-cultural, and adaptive technology factors, which influence the capacity for increasing CSA practices. Agriculture Extension, a government service of Belize, can facilitate effective CSA adaptations, specifically, an increase in mulching, soil nutrient enrichment, and soil cover, while working as partners within Maya farming traditions. These CSA practices can facilitate more equitable increases in crop production, milpa farm system sustainability, and resilience to climate change. However, there are several institutional and operational barriers in Extension which challenge their efficacy. Recommendations are presented in this study to reduce Extension barriers and promote an increase in CSA practices to positively influence food and livelihood security for milpa communities in southern Belize.

Keywords: climate-smart agriculture; socio-ecological systems; extension; Belize; milpa; food security; sustainability



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1. Introduction

For centuries, the traditional practice of milpa farming has been sustainable and reliable as the major food and livelihood source for Mayan milpa communities in southern Belize [1–4] as farmers allow areas to regenerate to a mosaic of forest succession stages and crop diversity [5–8]. In the last 50 years, however, the slash-and-burn aspect of the milpa has become less reliable and less sustainable due to environmental factors, such as hydroclimatic changes (i.e., droughts, flooding, hurricanes), forest and biodiversity loss, pests and crop disease, soil degradation and other factors in combination with socio-economic and governance factors such as poverty, population growth, land tenure, and marginalization [8–16]. These factors have multiple systemic impacts to the resilience of milpa communities.

Government response and action is needed to promote climate-smart agriculture (CSA) practices and positively influence food and livelihood security in Belize. CSA practices can “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” [17] p. 14. Government agricultural Extension service in Belize is in an effective position to promote CSA practices in Maya milpa communities because Extension works within the cultural traditions of the milpa system as partners in the process [10]. However, there are multiple barriers for Extension which challenge its efficacy, including

milpa farmers' land tenure, taxation, and poverty, and Extension's lack of operational budget, lack of technical training in CSA technologies, and a lack of staff [15]. Without a more effective Extension service facilitating CSA adaptations, there are implications for unsustainable crop production and food and livelihood insecurity in milpa communities of rural southern Belize [10,16–18]. The purpose of this study is to both examine three promising CSA practices—mulching, soil nutrient enrichment, and cover plants—and make policy recommendations to reduce Extension barriers to promote CSA practices for positive influences on food and livelihood security in southern Belize.

2. Background

Food and livelihood security for milpa farmers in southern Belize depends largely on Government response and promotion of climate-smart practices. Food security is the ability to provide present and future generations with a reliable food supply; it considers multiple factors and depends upon reliable crop production while sustaining a healthy ecological balance in a farming system [19–22]. Food security is dependent upon sustainable agriculture—the enhancement of crop production while sustaining a healthy ecological balance within agro-ecosystems [22]. Sustainable agriculture involves economic, environmental, social and other factors to promote food and livelihood security for communities [19,21].

2.1. Forest Loss and Climate Change Vulnerability in Belize

Rural communities in Belize are vulnerable to resource loss and degradation due to climate change, forest and biodiversity loss, and other factors [10,16–18]; these impacts, due, in part, to agro-industry and slash-and-burn agriculture, are exacerbated by rapid population growth, increased input of fertilizers, and farming on degraded soils [18,23]. There are implications for unsustainable agricultural systems and with that, the loss of forest, water availability, erosion control, and other needed natural resources and ecosystem services unless there is a strong government response in Belize. These ecosystem changes are “expected to threaten the sustainability of social, economic, and ecological systems” [24] p. 8.

Intact forests regulate climate, protect soils and water, and contain over 75 percent of global terrestrial biodiversity [25]. In Belize, the forest cover is roughly 60% but declining [26]. The growing rate of forest and biodiversity loss in Belize has compounding ecosystem pressures related to climate change, pollution, environmental degradation, and continual expansion of farms into forests [18,27,28]. Agriculture is the most significant anthropogenic driver of deforestation globally [11,25,29] and in Belize [12,26]; agriculture in the tropics directly impacts forest loss and is “responsible for nearly 85% of deforestation [and] 45% of deforestation in the humid tropics [is] due to shifting cultivation” [30], para. 17.

Large-scale 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 [24,31–33]. Climate change impacts perceived by farmers in Belize include a lack of rain, increased heat and sun exposure, offset rainy seasons, increased storm intensity, and an increase in pests and crop diseases [32]. In addition, climate change accelerates soil erosion and land degradation. These factors negatively impact crop reliability, which is linked to livelihoods and resource security, community health, cultural traditions, and other factors [15,34]. There are disproportionate adverse impacts related to climate and ecosystem change on the rural poor, who depend directly on natural resources for their food and livelihood security [12,15,17,35,36]; these impacts perpetuate a cycle of environmental degradation, poverty, and vulnerability to climate and ecosystem changes [37].

2.2. The Milpa Farming System in Belize

A milpa is a small-scale shifting cultivation system of subsistence farming [4,38] traditionally involving slash-and-burn and/or slash-and-mulch practices [39,40]. Mulching

and nutrient enrichment have also been a part of the traditional Maya milpa farming practice for centuries [40–42]. The milpa is a significant aspect of Maya culture and tradition as Maya identity, ceremony, community, and livelihood are all rooted in the milpa [9,43]. Milpa crop production is used for subsistence and selling at local markets [4,38]; milpas provide most of a family's need for food, wood, and income [11,44].

Milpa practices include clearing small areas of forest to plant a diversity of crops—primarily corn, beans, and squash—on nutrient-rich soil [7,44]. Through crop diversity, the milpa can sustainably increase milpa productivity and promote food security and food sovereignty, the “right to healthy and culturally appropriate foods” [43], p. 396. However, the milpa system is “not indefinitely resilient, particularly in an era of global economic and environmental change” [12], p. 75. Specifically, the slash-and-burn aspect of traditional milpa farming (clearing and burning of small areas of forests for crop rotation) is no longer sustainable with changing climate conditions, increasing human population, and natural resource competition [38]. Milpa farmers who exclusively practice slash-and-burn agriculture are more vulnerable to livelihood and food insecurity [10,12,17]. Burning reduces carbon stocks and the intense heat during burning can destroy critical root and seed banks [45]. Moreover, water-holding and nutrient status declines which dramatically increases “risks of accelerated erosion, water runoff, and crop failure in times of below normal rainfall” [46], p. 112.

2.3. *Managing Climate-Smart Agriculture (CSA) in Belize*

There is a need to manage resource loss and climate change vulnerability in Belize. Climate variability and extreme events (e.g., droughts, storms) are expected to become more frequent and damaging to water resources and agro-ecological systems in Belize in the coming decades [31]. The agriculture sector in Belize is especially vulnerable to climate change “not only due to its geo-physical location and hydro-meteorological hazards, but it is also due to the shortcomings of the current disaster risk reduction and response mechanisms to effectively mitigate the impacts” [31]. There is also a lack of institutional expertise to handle foreseeable climate change impacts [31].

The aim of climate-smart agriculture (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” [17], p. 14. CSA practices such as mulching and nutrient enrichment, along with improved land and water management, can result in higher and more stable yields, less production risk, increased system resilience to climate change, and lower greenhouse gas emissions. Therefore, CSA practices contribute to better food and livelihoods security for farming communities [34,47,48].

In Belize, the government vision for agriculture—the main engine of economic growth in Belize—incorporates several pillars including sustainable production and innovative technologies (Pillar 1), nutrition and food security, especially for rural populations (Pillar 3), and “climate change adaptation, environmentally sound production practices, conservation of natural resources, and risk management mechanisms” (Pillar 4) [49], p. 12. Continuing challenges to sustainable agriculture in Belize include: High and increasing poverty and unemployment, the rising inequality and access to food vulnerable populations, the steady decline in agriculture competitiveness, and increased scarcity of natural resources worsened by natural disasters and climate change [49]. These challenges are exacerbated by global financial instabilities which have negatively impacted employment, food and nutrition security, poverty, and inequity in Belize [49].

To improve the agricultural sustainability and reduce impacts of natural disasters and climate change, government action is needed, including the “promotion of 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” (31, para. 12). Increasing CSA practices can sustainably mitigate climate change impacts and support food security under a changing climate [15,50–52], while maintaining the health of ecosystems [20] and potential equitable increases in production in Belize. Otherwise,

“marginal areas may become less suited for arable farming” [17], p. 15, resulting in less food and livelihood security for milpa farming communities in Belize.

2.3.1. Mulching and Soil Cover for Water and Nutrient Holding

In Belize, climate-smart agriculture practices include mulching, soil nutrient enrichment, and soil cover; mulching avoids burning of debris and allows farmers to let organic matter decay on site. Mulching improves water holding capacity, soil organic matter (SOM), fertility, and stability, as well as reducing runoff and weed growth [12,42,47,51]. Further, mulching can improve soil water-holding by adding crop residues and manure to soil which effects soil properties and nutrient cycling, as well as lowering emissions [15,53]. Mulching has also been found to regulate surface temperatures, thus improving moisture and germination as well as other benefits for crop productivity [39,40,54].

Practiced by about half the milpa farmers in southern Belize’ Toledo District [32], mulching has similar planting and harvesting timing and is beneficial because it restores degraded soils, provides shorter fallow periods, and stabilizes crop yields [39,40,54,55]. Also, mulching in addition to soil cover, such as mucuna beans can lead to higher yields due to decreased on-farm erosion and nutrient leaching, lower grain losses due to pests, and reduced labor for weeding and fertilizer application [47,56,57].

2.3.2. Soil Nutrient Enrichment

Soil nutrient enrichment involves farming inputs that improve the soil conditions for production [39,40,54]. Soil enrichment practices can include adding chemical or non-chemical fertilizers and integrating effective microorganisms (EM) to break down slashed debris faster and build soil fertility [10,15]. There may be a need for farmers to purchase and use fertilization inputs in mulch systems, although that is debated in the literature. Two studies state fertilization inputs are essential to achieve good yields under fire-free conditions, although this cost may be offset from increased yields [15,58]. Other studies find that external fertilizer inputs were avoided with mulching where there was an increase in soil organic matter and water holding capacity [12,59].

There are some disadvantages to mulching and nutrient enrichment for farmers. Aside from the potential need to purchase fertilization inputs to enrich soil, mulching might also have a potential to increase snakes or animal vector encounters. Additionally, although mulching benefits are largely agreed to increase sustainability of yields, the increase in yield amount is debated due to slower nutrient release from the decomposing vegetation compared to burning [51]. Overall, mulching was found to have important farm system sustainability benefits, such as improving soil nutrients, regulating surface temperatures, improving moisture and germination, and increased crop productivity and sustainability [39,40,54].

2.4. Government Agriculture Extension in Belize

CSA practices and sustainable crop production depend upon government policies and action to shape agriculture adaptation response at the local level [17,32,49]. Government Extension services provide scientific knowledge and promote climate-smart agriculture practices, technologies, and innovations through farmer education and demonstrations [49,60,61]. Globally, Extension has a strong institutional expectation to inform, educate, and facilitate best practices for farmers [60] and to improve agriculture sustainability and promote “more resilient farming systems and practices” [31] para. 12 by working within the local socio-cultural traditions. Smallholder farmers are able to adapt to environmental changes using their traditional knowledge and experience and by adopting climate-smart agriculture adaptations [62].

In Belize, agriculture Extension is in an effective position to promote climate-smart practices in Maya milpa communities because they can work within the cultural traditions of the milpa system as partners in the process [10]. In doing so, Extension can influence adaptive capacity by transferring and promoting CSA technologies and site-specific tech-

nologies, such as water management, cover plants, enrichment, and mulching [10,12]. These practices facilitate a more productive and resilient agriculture system [31] and build resilience in milpa communities [2,10,63,64].

With Extension support, farmer capacity can be improved to innovate, solve problems, and adopt CSA practices; however, this will require continuous facilitation, capacity-building and support over time [56,65]. There are multiple barriers for Extension efficacy in promoting CSA practices in southern Belize, including governance, land tenure, taxation, poverty, and other challenges [15,49]. Further, there are institutional barriers within Extension including a lack of operational budget, lack of technical training in CSA technologies, and a lack of staff allocated from the national Extension office [49]; presently, there are four Extension Officers in southern Belize' Toledo District who are responsible for a large rural district of 52 communities [32].

2.5. Socio-Ecological Systems (SES) Framework

As part of the socio-ecological system (SES), milpa communities experience system impacts and can be more vulnerable to ecosystem changes such as climate change. Socio-ecological systems (SES) is an effective framework to study climate-smart agricultural adaptation in milpa communities in Belize [10,17,66] as SES is complex, systemic, cumulative, and intertwined with human systems [67]. This study examines perceptions of climate-smart practices from milpa farmers and agricultural Extension officers in southern Belize using a SES framework. SES is a flexible framework which considers the interrelationships, linkages, and synergies between multiple trans-disciplinary factors—social, economic, environmental, cultural, governance, justice and other factors; SES also involves inclusion and community-based partnerships and adaptive management [68–70]. Milpa farmers and Extension Officers in southern Belize can become more enabled partners in climate-smart solution finding. The socio-ecological system of milpa communities is a linked network where an impact on 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 [11,67,71].

3. Methods

This qualitative study uses Phenomenology and face-to-face interviews to examine common-lived experiences of climate-smart practices from the perceptions of milpa farmers and Extension officers. Phenomenology is well-suited for this study as it is both a philosophy and an inquiry strategy used to “develop an understanding of complex issues that may not be immediately implicit in surface responses” [72], p. 301. Phenomenology is useful to “investigate the relationship between participatory Extension methods and farmers changing to more sustainable practices” [73], p. 22.

The semi-structured interviews were both “purposive and prescribed from the start” [72], p. 302 and allow flexibility to ask participants deeper follow-up questions [32], in order to hear their stories, and to see the emergence of common experiences or phenomena through the participant's own words and descriptions [74–76]. During interviews, participants were asked both demographic questions and open-ended questions on topics such as milpa farming practices, socio-ecological system linkages to ecological changes (i.e., forest loss, climate change), barriers and conduits of sustainable agriculture practices, and other topics. Using Phenomenology, specific patterns, categories, and themes emerged from the interview data collected and analyzed [77–79]. New Mexico State University Institutional Review Board (IRB) approved all study protocols and interview questions; all interviews followed a voluntary and informed consent procedure.

3.1. Setting of the Study

In the southern Toledo District of Belize, three Extension officers and five milpa farmers from Pueblo Viejo and Indian Creek villages were interviewed for this study. Toledo District is the southernmost district in Belize; its population is nearly 50% Q'eqchi'

(Kekchi) Maya, 20% Mestizo, and 17% Mopan Maya. There are also Garifuna, Creole, East Indian, and Mennonite populations [80]. Milpa households in each village were selected using a stratified random design. The sample subpopulation of ‘primary (head) milpa farmer’ for each selected household was intentional to elicit the perspective of farmers who have the most direct knowledge of local forests, soils, and agriculture systems. Two participants selected were Maya cultural and political leaders in their villages who spoke to the importance of the milpa as part of their cultural practice. Interviews of Extension officers were conducted in both office and field settings; three (of the four total) Extension officers in the Toledo District in southern Belize were interviewed.

3.2. Data Analysis

Using the multi-perspectival framework of Socio-ecological Systems (SES), a combination of processes was used in the data analysis, including 1. Open (analytical), 2. Axial (reduction and clustering of categories), and 3. Selective coding [77,81–86]. These processes involved creating categories of like taxonomies and assembling structures or groups of themes into conceptual diagrams to show relationships and linkages [82]. Selective coding is a form of data synthesis where the intersection or integration of emergent thematic categories are first “crystallized” [10]. Crystallization uses multiple perspectives to blend data to produce thick description and knowledge of a phenomenon as well as a deepened, inclusive, multi-perspectival, and complex interpretation of it [85,86]. Selective coding results as the intersection of the main categories and themes [77] where categories are systematically related or conceptually linked in a multi-perspectival and holistic way [86]. From this data analysis and synthesis, dominate themes emerged and were categorized in the following Results section.

4. Results

Through socio-ecological system (SES) examination of interview data from milpa farmers and Extension officers, this study finds direct and indirect influences of climate-smart agriculture (CSA) practices—specifically mulching, soil enrichment practices, and ground and soil cover methods—on milpa farming sustainability. Table 1 summarizes results from interviews with milpa farmers and Extension Officers. Participants in this study perceived direct and indirect, (a) environmental, (b) economic, (c) socio-cultural influences, and (d) adaptive technology potential from CSA practices on the sustainability and resiliency of Belizean milpa communities.

Table 1. Summary of Results: Perceived Environmental, Economic, and Socio-cultural influences, and Adaptive Technology potential from climate-smart agriculture (CSA) practices (mulching, soil enrichment, and ground cover) on milpa sustainability in Belize.

Perceptions (Influences)	Environmental (Air, Soil, Water, Forests, Erosion, Pests)	Economic (Farm Income, Expenses, Tourism; Extension Budget)	Socio-Cultural (Culture, Traditions, Adaptation, Resilience)	Adaptive Technology (Potential)
Milpa Farmers	<p>Positive. Mulching/ground cover increase soil fertility and decrease erosion (compared to burning). Negative: More snakes. More time for decomposition. Clearing forests allows rotating on nutrient-rich soil- organic/less fertilizer use.</p>	<p>Positive. Stabilizes and increases production (subsistence and sale at small markets); non-chemical enrichment/cover plants = low/no cost. Shorter fallow periods. Intact forests increase tourism income. Mixed: perceived higher and lower fertilizer expenses (Overall: more yield = more income). Negative: More pests/ more need for costly pesticides.</p>	<p>Positive. Working directly with Extension to manage and sustain crop production with changing climate/seasons (temps/rainfall), uncertainty, insecurity. Slash-and-burn (only) not culturally sustainable (degrades); mulching adds nutrients.</p>	<p>Positive: Soil enrichment and intercropping: Need more information and financial support, technology/innovation (to mimic nutrient-rich forest soil) and keep forests intact. Use more organics (chicken manure). Pesticides/Integrated Pest Management: Need more information and assistance.</p>
Extension Officers	<p>Positive. Mulching and ground cover have erosion control, increases soil moisture (germination) and fertility, regulates soil temperature, reduces nutrient loss; reduces air emissions (no burning); better water management; sharing solutions for less pesticide use.</p>	<p>Positive. Sustaining production (proves Extension efficacy). Negative. Institutional and operational barriers (lack of budget, CSA training, staff); need to share resources (vehicles, fuel, staff) with other local government and non-government entities. Large district with 52 communities and only 4 Extension staff.</p>	<p>Positive. Working with milpa traditions for proven adaptations (i.e., pest and water management, soil enrichment) increases sustainable farming = security = community resilience, and Extension efficacy. Negative. Cultural barriers: Adaptive practices are slow-moving (but faster with young farmers); land tenure, poverty</p>	<p>Positive. Promoting non-synthetic soil cover and enrichment with integrated pest management, effective microorganisms (EM); and nitrogen-fixing and cover plants: Arachis, mucuna beans used by Amish/Mennonites).</p>
Overall	<p>Positive. Increased soil nutrients, ground cover and moisture, erosion control, managing crop pests and disease.</p>	<p>Positive. Sustained production). Mixed: Both higher/lower fertilizer expenses. Negative: Lack of information; higher costs for pests/pesticides. Extension barriers (lack of budget, training and staff)</p>	<p>Positive. Adaptation = sustainable farming. Adapting cultural practices maintains cultural traditions. Negative: Socio-cultural barriers adopting new CSA technologies.</p>	<p>Government vision and priority for sustainable agriculture and community resilience to climate change impacts (food insecurity, livelihoods, storm and disaster resilience).</p>

4.1. Environmental Influences

Milpa farmers and Extension officers perceived positive environmental influences from CSA practices on milpa sustainability. For the purposes of this article, environmental influences, include impacts to air quality, soil nutrients, soil water holding, land erosion, and pests and disease. This study finds CSA practices of mulching, soil nutrient enrichment, and soil cover have positive environmental influences for increasing soil nutrients, ground cover and moisture, controlling erosion, and managing crop pests and disease. Extension officers interviewed for this study perceived both mulching and nutrient enrichment to be climate-smart and beneficial for milpa famers.

4.1.1. Benefits from Mulching (vs. Burning)

Milpa farmers and Extension officers perceived less impact from mulching over burning. All milpa farmers interviewed for this study practice slash-and-burn; one farmer explained his process: “I will soon start to chop bush, and then it dries, and then [I] burn it, and then plant it. You chop more bush to plant more [crops].” Some also practice mulching; one milpa farmer described his preference for mulching over burning due to the benefit of less erosion: “[We] just leave [debris] there and it’ll get rotten, right? Leave the stump right there, because the stump—it holds a lot of soil [and] when it’s raining, it won’t flush off. So, just leave the stump right there until it gets rotten”.

Extension Officers interviewed explained mulching provides effective ground cover and erosion control; also mulching keeps more moisture and fertility in the soil. Whereas, burning exposes and heats up the soil, causing nutrient loss. An Extension officer explained the benefits of leaving the vegetation to rot in the mulching process: “[The grass] 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.” One Officer explained burning and not leaving debris on the soil causes erosion: “. . . then you have a long drought [and then] how do you keep moisture? And, those are the things that we have to make farmers aware of—it’s a chain of reaction.” There is a disadvantage to mulching in “that it’s too bushy and people don’t want to go in there . . . because it attracts maybe snakes and other things” [32]. However, there was an overall positive environmental influence of mulching, nutrient enrichment, and soil cover on milpa sustainability.

Extension Officers see other CSA benefits with mulching, including reduced air emissions, better water management, and the use of non-chemical inputs for crop pests and disease. Climate change creates the condition for unreliable water and a higher incidence of crop pests and disease; one Extension Officer described how this affects crop production: “A high incidence of pests (are) noticeable now . . . so, all of these things—and a limited water supply—all of these things are affecting agriculture, in general . . . and those things limits our work as well.” He stated that years ago, they did not have to think about the climate, but now they have to “be [climate] smart.” An Extension officer stated they “need to do a little bit more public awareness in terms of the negative effects [of burning]” due to air pollution, global warming, and other effects.

4.1.2. Benefits of Nutrient Enrichment and Soil Cover

Milpa farmers traditionally rotate crops on nutrient-rich “black” soil due to the nutrient depletion in farmed soil over time [10]. One farmer stated if there were soil enrichment assistance for farmers—specifically information and financial assistance for inputs—he would not need to “chop” forest to use the enriched soil. Extension Officers want to demonstrate to farmers that climate-smart alternatives (i.e., mulching and enrichment) work. Increasing nutrient enrichment such as effective microorganisms (EM) and using nitrogen-fixing cover plants can benefit milpa farmers. One Officer educates farmers and promotes EM. He stated, “A lot of farmers, they are starting to use organic material—meaning chicken manure. They are using a lot of EM agriculture to build up the soil fertility.” The same officer also explained the benefits of mucuna beans for nutrient enrichment:

We have some farmers that benefit from the training as well, because, at some point, we introduce some types of fertilizer that you incorporate in the soil . . . [for example] mucuna beans: The Mennonites [presuming he means 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.

Another Extension officer promotes arachis (*Arachis glabrata*), a wild peanut perennial. Arachis is useful for milpa farmers as an effective ground and soil cover and as a nitrogen-fixing plant. These climate-smart practices mimic or replicate the nutrient cycling in forest ecosystems while allowing for sustainable production of agriculture [46].

4.2. Economic Influences

Milpa farmers and Extension officers perceived mostly positive and some negative economic influences from CSA practices on milpa sustainability. For the purposes of this article, economic influences include impacts to farmer income, farmer expenses, farmer time, Extension expenses, and impacts to alternative income (tourism). This study finds climate-smart practices, particularly mulching, soil nutrient enrichment, and soil cover, have overall positive economic influences for increasing farmer income and reducing farmer expenses. However, Extension's limited budget to promote CSA practices is a barrier.

From an economic perspective, milpa farmers are concerned about maintaining production (for subsistence and selling at local markets) and reducing costs and expenses—related primarily to controlling pests and disease and adding fertilizer inputs—in their daily farming practice. Some farmers interviewed worried about increasing pests resulting from climate warming; their lack of knowledge of pests and pesticides management was a top concern [32]. Most often in milpa communities, pest management includes the use of chemical fertilizers and pesticides, which are an additional cost for farmers [32].

4.2.1. Soil Enrichment Cost-Benefit

Soil enrichment involving fertilizer inputs (chemical or nonchemical) is a cost to farmers; all farmers interviewed for this study stated they buy and/or use fertilizer inputs. Although an upfront cost, one study concluded that using fertilizers increases farmer yields enough to compensate for fertilizer costs [58]. Moreover, adding nonchemical enrichment or soil cover (i.e., arachis) can be low to no cost. Milpa farmers who rotate crops in cleared forest areas avoid fertilizer cost by using nutrient-rich black soil. One farmer explained that otherwise, the soil gets too dry and hard; “but, if we change every year, it doesn't need fertilizer. Yah, just normal planting—organic . . . That's why we maintain for we [sic] forest.” Conversely, another farmer explained that keeping forests intact is important for his village's economic development and tourism industry:

We understand the slash and burn is [bad]—sometimes for humans, for us and also for a wildlife—and, so, we are trying to avoid that now. We are working very closely with the village leaders [to develop potential tourism in the village] . . . because we need to take care of our forest, including creeks, rivers, and streams, and so forth.

4.2.2. Extension Barriers

Climate change negatively impacts farmer food security and livelihood which can impact Extension efficacy in promoting and facilitating sustainable agriculture practices in milpa farming communities [32]. However, there are institutional and operational barriers in Extension services, including a lack of government funding for daily operating, a lack of technical training in CSA technologies, and a lack of staff. One Extension officer noted: “We need support from [the national office] because we cannot do it alone . . . We need to prioritize [climate-smart] topics because everything now is climate change . . . everything is focused around climate change and resilience.” To cope with the low numbers of staff, Extension officers stated they have to collaborate and share resources with other government agencies and nongovernmental organizations to carry out some aspects of their Extension duties (i.e., sharing vehicles to reach farmers in remote communities).

4.3. Socio-Cultural Influences

Milpa farmers and Extension officers perceived both positive and negative socio-cultural influences from CSA practices on milpa sustainability. For the purposes of this article, socio-cultural influences are defined as impacts to farmer traditions and heritage, adaptation responses, adopting new technologies (i.e., effective microorganisms), and community resilience. This study finds climate-smart practices, particularly mulching, soil nutrient enrichment, and soil cover have overall positive socio-cultural influences for

maintaining milpa socio-cultural practices and traditions. However, there are barriers for some farmers in adopting newer CSA technologies and practices.

4.3.1. Climate Change Impacts to Milpa Culture

Milpa farmers and Extension staff perceived direct impacts from climate change—more intense sun/heat, lack of rain, offset rainy season, increase pests and disease [32]; in turn, these impacts effect the cultural traditions of milpa communities and their ability to provide corn and beans for subsistence. One farmer stated: “I am waiting for that rain because I have some corn that is (small) [demonstrates small size] that haven’t gotten water for a good while—so, I’m hoping and wishing that this week it will soon rain.” Another stated: “I tried to plant vegetables but he [sic] no grow—he dead. I planted, but he neva (never) grow good. I don’t know why, because maybe he got sun too much;” and “the rains are different than what they were because, it doesn’t rain too much . . . I am worried about crops—worried about the weather.” A third farmer described the offset rainy season: When they expect the rainy season, there is strong sun and heat; they don’t know “which time is for the right time” to plant. He explained: “We need to study the climate changes and the temperature (so we can) try to manage.” This farmer also explained the exclusive practice of slash-and-burn, a traditional form of milpa agriculture, may not be culturally sustainable:

The only way we could damage [the milpa farming culture] for us is if we continue to slash and burn, and burn, and slash and burn—and, we believe that one day our crop will never come out good again because the fertile[ity] of the ground is washed off, so everything goes in the creeks, in the river; and, the land becomes poor and poor and poor and poor—and, so, now, we don’t want to practice that because we understand the situation there. So, we believe that to maintain the soil, to treat the soil in a proper way . . . not to cut down the trees or not to burn it—even though if you want to fall something—but, leave it there—just, leave it there, and it’ll get rotten.

4.3.2. Extension Barriers

Extension Officers interviewed for this study stated that climate change impacts to milpa farmers creates a barrier for Extension service efficacy. One Officer stated climate change is a real factor now: “A high incidence of pests (are) noticeable now . . . so, all of these things—and a limited water limited water supply—all of these things are affecting agriculture, in general . . . and those things limit our work as well.” Another Extension Officer added: “Climate change is very, very important because all these pests and disease . . . in a hot climate or little water available—always climate change issue is very critical now and there . . . and we make [farmers] aware of that”.

4.3.3. Cultural Adaptations and Adaptive Technologies

Increasing CSA practices such as soil nutrient enrichment can help milpa farmers plant on soil which mimics rich black soil (i.e., converted from cleared forest). However, some farmers perceive this socio-cultural adaptation is not needed; one farmer stated he prefers to clear forest because “black soil is better [to farm]” and that “works for us.” Two farmers interviewed were interested in learning new technologies and adapting their practice; one stated an interest in intercropping and effective microorganisms (EM) for soil enrichment:

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 . . . Yes, yes—that would be interesting . . . interesting. You bring some soil, you just mix it up, and plant some there.

Extension officers are promoting milpa farmers increase climate-smart practices, including slash-and-mulch farming and soil nutrient enrichment, as they are beneficial and sustainable milpa practices [32] which can increase farmer production and income. One Officer stated about half of the farmers in the district practice mulching; however, there

is a need for more public awareness of the negative effects of slash-and-burn practices by making it a priority to show farmers proof of workable CSA practices:

We need to continue to educate the farmers, right(?) . . . because whenever you do your field visit and so on, you can see that some farmers, yes, they do adaptive technology very slowly; others, they go a little bit faster . . . but some of them it's very hard. So, what I have found is that (we should) continue capacity-building, education . . . (and) at some point, of course, especially the young farmers that are coming up—try to teach them the right way of doing agriculture—sustainably.

Another Extension officer is trying to educate and promote nutrient enrichment technologies such as effective microorganisms (EM), mucuna beans, and arachis: “A lot of farmers, they are starting to use organic material (such as) chicken manure, right? They are using a lot of EM agriculture to build up the soil fertility.” He explained the benefits of mucuna beans:

We have some farmers that benefit from our training . . . we introduce some types of fertilizer that you incorporate in the soil . . . (for example) mucuna beans: the Mennonites [presuming meaning 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.

He also explained the benefits of arachis, a wild peanut perennial; arachis can be used for chicken feed in a mobile chicken coop. He explained arachis is an excellent ground and soil cover and as a nitrogen-fixing plant.

4.3.4. Extension Partnership

Extension Officers perceived milpa farming practices are sustainable due to cultural traditions and knowledge passed down through generations. However, the Officers interviewed stated milpa traditions will only stay sustainable if farmers adapt to include CSA practices. An Extension supervisor in the national office stated district Extension officers can work within the cultural traditions of the milpa system to promote sustainable practices:

[We need] a way 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. It's a learning process, not to challenge traditional [farming methods, but try to promote] a few [effective] agricultural practices like soil conservation, irrigation systems, and integrated pest management [87].

With time and resources, Extension Officers are in an effective position to promote sustainable agriculture production because they are partners with milpa farmers in both maintaining traditional milpa practices and adopting more sustainable CSA practices [15].

5. Discussion

The purpose of this study is to both (1) examine three promising climate-smart agriculture (CSA) practices—mulching, soil nutrient enrichment, and cover plants—and (2) make policy recommendations to reduce Extension barriers to promote the CSA practices for positive influences on food and livelihood security in southern Belize. From interviews with milpa farmers and Extension officers in Belize, this study finds CSA practices were perceived to have overall positive socio-ecological system influences on Maya milpa farming communities, including: (a) Economic, (b) Environmental, and (c) Socio-cultural influences, as well as (d) Adaptive technology potential; these influences were perceived as conduits for sustainable milpa agriculture. A flow diagram or conceptual impact model (Figure 1) of the influence categories was constructed (via PowerPoint software) using this study's perception data gathered during interviews. The model shows relationships and linkages between the SES influences as they relate to CSA practices.

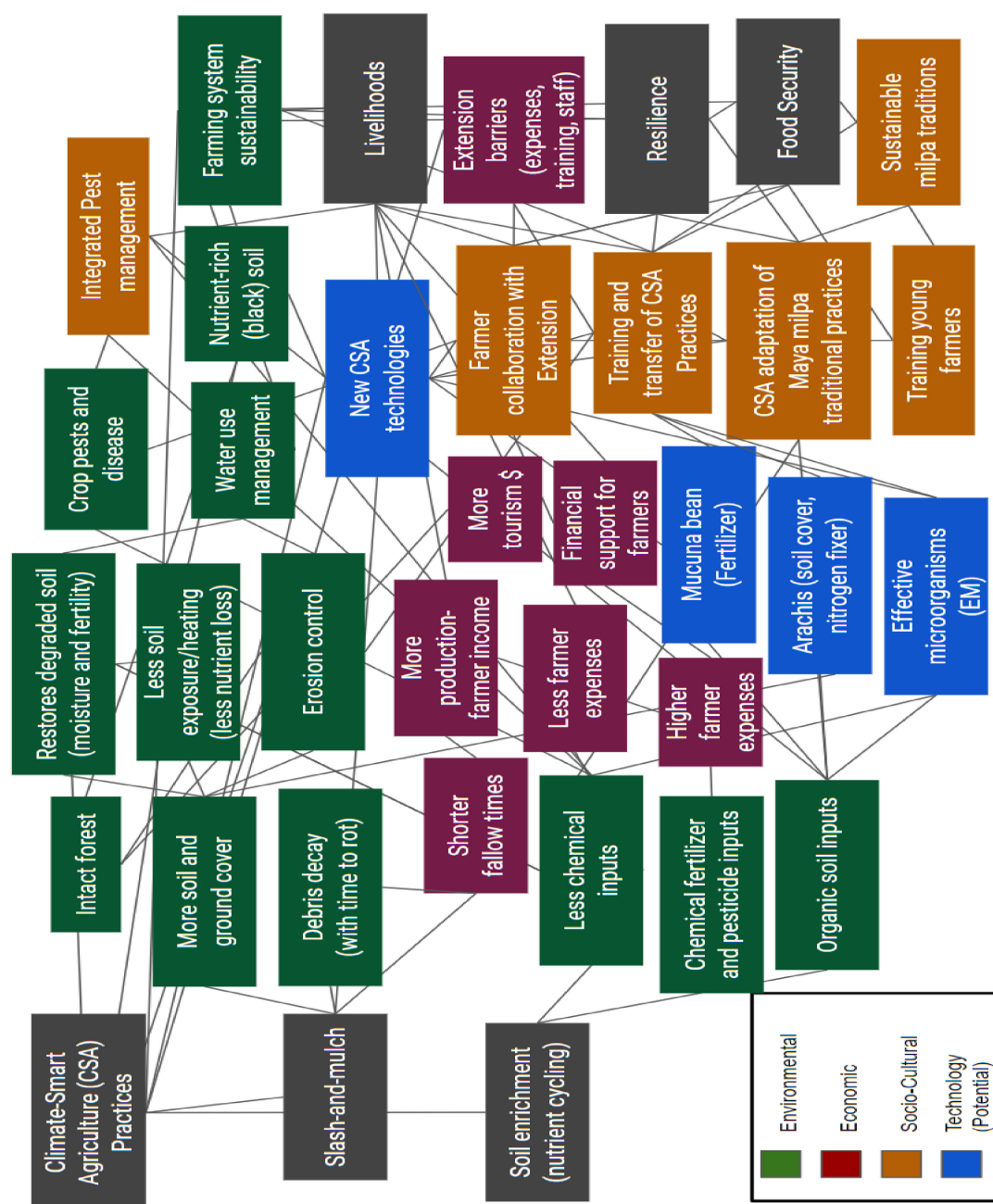


Figure 1. A Socio-ecological Systems impact model from this study’s climate-smart agriculture (CSA) influences—environmental, economic, socio-cultural, and adaptive technology (potential)—on milpa farming sustainability and resilience in southern Belize.

Figure 1 is based on the conceptual framework by SES architect Dr. Elinor Ostrom, widely considered to be the foremost researcher on SES; her model shows a multilevel and multi-perspectival examination of SES factors, drivers, interactions, and outcomes with implications for adaptive management, multiple stakeholder coordination, collective action, and community-level application [68–70]. Other similar models informing Figure 1 which demonstrate complex, multi-perspectival linkages in a socio-ecological system include Parrot, et al. [70], Flora and Flora [88] community capitals, Cote and Nightingale [89], Gonzales, et al. [90], and Tenza, et al. [91]; these works show an emphasis on feedback dynamics where human systems can shape ecological components and vice versa.

The data analysis processes of selective coding and crystallization described in Section 2 created a complex and multi-perspectival interpretation where dominant themes

emerged. The major influence categories were systematically linked [77,86] and show multiple intersections which directly and indirectly relate to CSA practices in milpa communities. In Figure 1, Environmental influences are represented by green boxes, Economic influences are burgundy, Socio-cultural influences are gold, and Adaptive technology potential are blue.

Figure 1 demonstrates linkages that can be useful to inform government policy and action. Intersections of linkages can be used to help identify priority areas which may have implications on the larger socio-ecological system. For example, the model demonstrates how soil enrichment practices are linked to potential adaptive technologies such as mucuna beans, arachis, and effective microorganisms; those are linked to less chemical inputs, a reduced need for costly fertilizer inputs, more soil stability by keeping forests intact (i.e., not needing to cut forests for black soil), maintaining Maya socio-cultural traditions, and so on—altogether demonstrating a positive influence on the larger milpa socio-ecological system. Therefore, one Extension intervention (i.e., facilitating increased use of mucuna beans) can have positive impacts to other parts of the milpa socio-ecological system. Overall, the model shows increasing CSA practices of mulching, soil enrichment, and cover plants can foster higher crop production with more resource stability; the implications for this can mitigate disproportionate climate change impacts related to poverty, climate justice, resilience, and food and livelihood insecurity in milpa communities.

Figure 1 is intended to be a small picture of an otherwise larger and more complex milpa agroecological system with multi-dimensional, dynamic, non-linear (circular) feedbacks and flows [32]. Understanding these system relationships—and how each factor functions in the complex whole of the SES—is important as each decision a farmer makes to adopt CSA practices can advance the entire milpa agriculture system further [92,93]. Elements of Figure 1, specifically related to Extension and government action, were used to inform the policy recommendations in this study.

6. Conclusions and Policy Recommendations

From interviews with milpa farmers and Extension officers in Belize, this study finds climate-smart agriculture (CSA) practices of mulching, soil nutrient enrichment, and soil cover can have overall positive socio-ecological system (SES) influences on milpa sustainability in southern Maya Belize communities. Although milpa farming has been sustainable for centuries, global climate change and other factors such as poverty, population growth, forest loss, and land degradation have made the practice less so over the last 50 years. Promoting the increase of CSA practices on milpa farms has overall positive (a) environmental, (b) economic, and (c) socio-cultural influences and (d) adaptive technology potential on milpa sustainability, food and livelihood security, and resilience. By examining the perceived SES influences of CSA practices, this study makes policy recommendations to reduce government Extension barriers to promote the CSA practices for positive influences on food and livelihood security in milpa communities of southern Belize.

Promoting CSA practices necessitates Government involvement and action. Agriculture Extension in Belize is in an effective position to facilitate an increase in CSA practices because it has a strong institutional expectation to inform, educate, and demonstrate best practices to the public. Working within milpa cultural traditions, Extension Officers can promote an increase in climate-smart practices, while including milpa farmers as partners in the process. Specifically, promoting the practices of mulching, soil nutrient enrichment, and soil cover can have positive socio-ecological system influences and potential equitable increases in crop productivity. Government agriculture Extension services are needed to promote CSA practices in the milpa communities they serve. Recommendations here are targeted to Government Extension services in Belize at the national and district levels:

1. Increase District operational funds (i.e., vehicles, fuel), technical training, and the number of trained officers to enable Extension to promote farmer adaptation such as mulching, soil nutrient enrichment, and other nonchemical technologies (e.g., effective microorganisms, mucuna beans);

2. Use socio-ecological system and agroecological research and analysis to inform policy in adaptive management for climate and ecosystem changes; producing food in a more sustainable way involves multidisciplinary factors and a participatory and action-oriented approach to sustainable and just food systems [66,94–96]; and
3. Develop appropriate scaling [97] to enable local village and farmer leadership in CSA technologies [98] through capacity-building, community participation and collective action, and sustainable-focused programs, such as farmer field schools and youth involvement programs. Working within the cultural traditions of milpa farmers and including farmers as partners in the process, Extension services can promote CSA practices for a more sustainable milpa farming system for food and livelihood security in southern Belize.

Incorporating these recommendations while continuing to work within the cultural traditions of milpa farmers as farmers as partners in the process, Extension services can promote CSA practices for a more sustainable milpa farming system for food and livelihood security in southern Belize.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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